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UAVs and Manned Aircraft—Increasing Effectiveness and Survivability

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Director's Notes

CDR Andrew (Andy) Cibula, USN

While earning my M.S. in Aeronautical Engineering at the Naval Postgraduate School (NPS), I had the opportunity to work with several staff members of the unmanned aerial vehicle (UAV) programs. I was there because my thesis involved testing and evaluating the flight, thrust, and control properties of a generic UAV with the anticipation of using that data to develop a future automated flight control system. The UAV I worked on never made it into free flight, but it did provide information that was used to develop another UAV. That UAV, which is a favorite in the Aeronautics Department, was a one-quarter size Pioneer aircraft that was affectionately named the "Bluebird." The Bluebird was used in a variety of tests to evaluate a number of different flight configurations and other such research. It was remotely controlled, much like a model airplane. That was until the avionics guys got their paws on it.

The avionics guys were anxiously looking for a vehicle to outfit with an automated flight control system. So they took the information gained from my automatically controlled UAV and tried to put a flight control system on the Bluebird. The day came when it was time to fly the UAV; it took off and flew like a champ until it suddenly rolled over and plunged to earth. The avionics guys were able to regain control just in time to avert a catastrophe and landed the UAV safely. The aeronautic guys were immensely relieved and the avionic guys immediately decided to try the maneuver again, hoping to repeat and identify the problem. They did, and you guessed it, the Bluebird made one very uncontrolled final landing—never to fly again. The aeronautics guys were stunned and heartbroken. The avionic guys asked, "Hey, you got any more planes?"

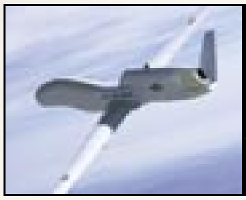
That may not be exactly how it happened, but it is close enough to articulate my point. So, "what is the point?" Well, this story illustrates the disparate philosophies about the value of the UAV. Some (i.e., the avionics guys) feel UAVs are expendable and should be treated as such. Others (i.e., the aeronautics guys) believe that the UAV should be considered a non-expendable asset and should be protected just like any other high-value Military aircraft. These views can be generally applied to DoD in their attitude toward UAVs. Before Afghanistan, it seemed that most viewed UAVs like the avionics guys—as an expendable asset that we could send anywhere regardless of the risks involved. Lately, the general consensus seems to be gradually leaning toward the attitude of the aeronautics guys. UAVs have become one of the most valued assets in combat today, as is illustrated in Operation Enduring Freedom. Field commanders are becoming more and more reliant on UAVs in directing the tactical picture. UAVs are also becoming a significant intelligence gathering platform and are being used to supplement national intelligence assets at an ever-increasing level.

As important, UAVs and their payloads are getting expensive. The Global Hawk is priced anywhere from \$25M to \$75M, depending on who you talk to. And the Predator A, while only costing \$3 to 4M for the airframe, is carrying payloads that are 2 to 3 times that amount. So now, we are operating vehicles that are not only extremely valuable in the tactical picture, but costly as well. Let's throw one more issue into the mix—the bad guys know this as well. Now, we have these valuable, costly, and highly targeted vehicles and recent conflicts have shown what happens when you put all this together—you tend to lose a lot of aircraft. This has been the case in Afghanistan, Kosovo, and Iraq. UAVs are being targeted with increasing frequency and UAV combat losses are mounting.

For these reasons, this issue of *Aircraft Survivability* is focused on the survivability of the UAV. One article, written by Mr. James Young of the Naval Air Systems Command, Survivability Division, describes numerous JTCG/AS projects currently underway that are trying to enhance the survivability of UAVs. This includes minimizing the acoustic signature of UAVs, increasing operator situational awareness, developing miniaturized countermeasures, and completing vulnerability assessments on deployed UAV aircraft. Another article by Major General Bergantz, Program Executive Office for Army Aviation, describes some of the UAV-manned aircraft teaming work being conducted by the Services. Assessing these "system of systems" between manned and unmanned vehicles is the foundation of anticipated future battlefield operations. Although there is much talk of UAVs dominating future battlespace, chances are there will always be manned and unmanned vehicles operating in close coordination to increase effectiveness and also increase air vehicle survivability.

In summary, I think we have a good start in dramatically increasing the survivability of unmanned aircraft. However, to be completely successful in integrating survivability features in UAVs, we must continue to change the mindsets of all the "avionics guys" involved in UAV acquisition and operations. Now UAVs are too valuable and costly to be considered expendable. Hopefully, the hard lessons learned will be passed on to more people—unmanned aerial vehicles are not that expendable—especially if you really need them.

CDR Andrew (Andy) Cibula
Director, JTCG/AS Central Office



Manned and Unmanned Experimentation

Enabling Effective Objective Force Operations

■ by Major General Joseph Bergantz, Mr. Jim Delashaw, Mr. Steve MacWillie, and Mr. Don Woodbury

Major General Joseph Bergantz

Over the past five years, U.S. Army aviation has been exploring the operational synergy of manned and unmanned (MUM) systems working as a "system of systems" team on the future battlefield. The man-in-the-loop simulation experiments conducted at Fort Rucker, Alabama provide an operational assessment of MUM air maneuver teams in Objective Force operations. The knowledge and experience gained from these experiments continues to influence aerial platform design, identify new tactics, techniques and procedures (TTP), and define future concepts of operations (CONOPS). Ultimately, the information collected will assist in defining a credible air maneuver capability for the Objective Force. This article will address past, present, and future modeling and simulation efforts, design considerations (i.e., areas for trade-off analysis), alternative technologies, and future activities supporting U.S. Army transformation.

The results of U.S. Army Training and Doctrine Command's (TRADOC) warfighting assessments, studies, and modeling and simulation exercises clearly indicate—

Objective Force operations will be characterized by developing situations out of contact; maneuvering to positions of advantage; engaging enemy forces beyond the range of their weapons; destroying them with precision fires; and, when necessary, by tactical assault at times and places of our choosing.

Initiative	LOC	Survival	UAV Alt	CDAS	Lethal	Design
MUM I	0-1	S	High	N	N	FW
MUM II	2-4	S	High	N	N	FW
MUM III	2-4	S	High	P	N	FW
MUM IV	2-4	S	H/L	P	N	RW
AMUST	2-4	S	Low	N	N	FW
MANPADS	0-1	NA	Low	N	Y	RW
FAST	2-4	P	H/L	Y	Y	FW, RW
UCAR	2-5	P	Low	Y	Y	RW

Legend:
LOC= level of control
S = secondary
P = primary
N = no
Y = yes
FW = Fixed Wing
RW = Rotary Wing
CDAS = cognitive decision aiding system

Table 1. Studies and experiments with manned and unmanned (MUM) teams

Such a wide range of CONOPS can only be effectively and efficiently addressed through the application of an integrated joint and combined arms "system of systems" capability. Table 1 summarizes the key features of the studies discussed herein.

Introduction

The U.S. Army Aviation Center, with support from TRADOC, the Comanche Program Office, and industry, have conducted four MUM concept experimentation programs (CEPs) over the past five years. The focus of these experiments was to determine the operational value and synergism gained from teaming manned and unmanned aerial platforms and to understand how these teamed platforms could best support Objective Force operations. The aspects of teaming which required the most attention were the level of control of manned systems over unmanned systems, and the integration levels necessary to achieve military worth and utility. In most of the experimentation, secondary consideration was given to ***team survivability,*** which was a measured item of interest influencing military worth and utility. As these experiments were completed, information was collected about the man-machine and machine-machine interfaces, and the survivability attributes necessary to support effective teaming operations.

With support from the Defense Advanced Research Projects Agency (DARPA), the U.S. Army Aviation Center conducted a top-level study to assess the characteristics and operational value of an armed unmanned aerial vehicle (UAV) teamed with manned systems. The results of this study contributed to the vision for the Unmanned Combat Armed Rotorcraft (UCAR) program.

Why manned and unmanned teaming?

Manned systems provide the critical human dimension well forward *on-site—not from a distance*. They develop an ***all-around*** situational awareness and understanding, by analyzing and combining sensor data with their "***feel***" for the battle. A soldier is able to immediately ***adapt*** to the unforeseen or anticipated situation and find the best way to utilize his equipment—even when it does not function as advertised. Man-in-the-loop describes the eyes-on *agility of thought* and *focus of purpose* to carry on when the situation is unclear, complex, communications fail, systems malfunction, and people die. Until technology can truly replicate the complex intangible functions performed by soldiers, teaming will remain the solution.

MUM Teaming Experiments

In 1997 the U.S. Air Maneuver Battle Laboratory (AMBL) began to explore the synergy of MUM systems teamed together. The focus was to define the optimum level of control between manned and unmanned systems. Each MUM experiment increased the level of control until level 4 was attained, and then level 4 control continued within subsequent experiments and studies.

MUM I identified a "base case" of MUM systems—the Comanche and the UAV—operating independently in the same battlespace, performing different missions for different commanders. The UAV performed its Intelligence, Surveillance, and Reconnaissance (ISR) mission while the Comanche performed its Armed Reconnaissance mission in support of the maneuver commander. Level 1 control was achieved through direct radio communications between the Comanche and the UAV Ground Control Station (GCS). This communication link enabled the Comanche crew to direct the UAV operator actions through the GCS communication network. The UAV operators examined certain terrain areas or tracked moving targets and provided that information to the Comanche crew. In the case of mobile SCUDs, the UAV would monitor the hide sites. Once the SCUDs began moving, the GCS would inform the manned system and the Comanche would destroy the SCUD. MUM I laid the foundation of teaming CONOPS and TTPs that were used in subsequent experiments. The analytical results of teaming in MUM I areas follows—

- 10 percent reduction (average) of time required to conduct the tactical reconnaissance mission
- 15 percent increase in identifying targets
- 20 percent increase in reporting High Payoff Targets (HPT)
- 30 percent increase in Commanders Critical Information Requirements (CCIR)

Additionally, MUM I demonstrated that mid-altitude operations of the UAV made it vulnerable to radar-guided air defense threats.

MUM II examined man-machine integration by increasing the Comanche J5 control of the UAV from level 1 to level 4. The Comanche and UAV GCS crews planned their mission collaboratively towards a common objective, and used the strengths of one platform to offset the weaknesses of the other. In the division of labor, the UAV was generally used to sweep the open terrain areas and the Comanche was used to look in the nooks and crannies of the hills and to put "eyes on target" using target detection cues from the UAV to prevent fratricide of friendlies or non-combatants. UAV visual sensor video was simultaneously passed directly to the Comanche and GCS. This direct communication with Comanche enabled the capability to provide immediate maneuver information. The GCS was eliminated as the "middleman." The Comanche crew directed the employment and maneuvering of the UAV through simulated digital communications directly to the GCS. The Comanche crew planned their mission with the intent of using the UAV as a remote sensor. They controlled the azimuth, depression angle, and zoom factors of the UAV sensor payload, and imported imagery directly into the cockpit. The addition of UAV platform control to the Comanche crew tasks increased workload beyond the crew's capability. The man-machine interface and integration had become so disconnected that the mission could not be accomplished. The results of MUM II are as follows—

- Visual imagery from the UAV to the cockpit of the manned system was used to increase the effectiveness and survivability of the team.

- Manual control of the UAV sensor payload **plus** control of the UAV platform operations by the Comanche crew could not be conducted effectively. Team survivability was negatively affected by the cognitive skills paralysis that occurred at the point of task overload.

MUM III continued the development of concepts for the interface and integration of the UAV and Comanche. From previous experiments we learned that information must be presented to the Comanche crew in an understandable and innate manner. Consequently, imagery was presented the same way for both the UAV sensor and the Comanche sensor. UAV imagery was processed through the Comanche's aided target detection classification (ATDC) system and then presented to the crew in the form of a cropped image. Additionally, the source—own ship or UAV—of the imagery was identified in the image. This improved pilot-vehicle interface (PVI) integration and increased mission performance. However, workload was still quite high. The UAV was integrated, but at the expense of Comanche performance. We then examined the use of Rotorcraft Pilot's Associate (RPA) technology to reduce crew workload.

The results of MUM III are as follows—

- VTOL TUAV platform and sensor characteristics enabled employment at stand off ranges for security (overwatch) of both air and ground maneuver forces

- VTOL TUAV, employed at low altitudes, could utilize the survivability enhancements provided by terrain masking and radar clutter

- Simulation integration of MUM capabilities must mature prior to further exploration of UAV control levels 4 and 5

- Addition of RPA technology resulted in no degradation of crew performance when teamed with the UAV

- UAV, coupled with RPA technology, improved the overall mission effectiveness of the manned-unmanned team

MUM IV was designed to capitalize on cognitive decision aiding to enable the Comanche crew to realistically manage the workload associated with employing level 4 control of multiple UAVs. The MUM IV man-machine interface was designed based on functions and capabilities from MUM III. This PVI was intended to enhance crew utilization of products from the UAV sensor suite, as well as to direct flight and sensor operations. Decision-aiding technology from RPA and follow-on programs provided necessary task assistance. Unfortunately the limited CDAS tools available for integration were not mature beyond a rudimentary level. One very clear result from MUM IV is that ***cognitive decision aiding tools are absolutely necessary*** if the Objective Force concept continues to add remote weapons and sensors to unmanned systems.

MUM IV examined the number of UAVs a manned system can reasonably control. Given the level of automation simulated, the answer appears to be two UAVs. We plan to identify the mix of systems at the team, platoon, and troop level. The results of MUM IV will be available in December 2002.

Advanced Manned and Unmanned System Technology

The Advanced Manned and Unmanned System Technology (AMUST) Science and Technology Objective (STO) effort demonstrated teaming of manned helicopters with UAVs using level 4 control. AMUST seeks to mature technology from the RPA Advanced Technology Demonstration (ATD). The technology is used to manage routine aspects of UAV operations and enable the manned system's crew to "manage by exception" those items requiring their decisions. AMUST is integral to the technology solutions sought for the Hunter Standoff Killer Team (HSKT) Advanced Concept Technology Demonstration in FY05, and will influence the design of the Associate Technology for FCS.

Future Combat Systems Aviation Systems Technology (FAST) Study

The objective of the FAST study was to assess the potential contributions of aviation systems to the survivability and lethality of a Future Combat System (FCS) equipped force. FAST examined a notional FCS Brigade within the Operation Restore Peace scenario that had recently been used by the U.S. Army to assess the Interim Brigade Combat Team (IBCT). In this scenario, the early entry Brigade suffered heavy losses due to the enemy's ability to counter our sensor overmatch. FAST introduced a layered UAV architecture that enabled situational understanding and standoff target identification and prosecution. The UAV architecture included short-range reconnaissance assets that were organic to individual vehicles, an armed UAV that provided dedicated reconnaissance and attack assets that enabled identification and prosecution of camouflaged and concealed targets at depth, and high-altitude surveillance and communications relay assets that provided target acquisition cues to the organic and armed systems as well as to ground-based indirect fire systems. The FAST study concluded that the addition of a layered UAV architecture dramatically improved the survivability and lethality of the early entry Brigade. Of the capabilities examined, the armed UAV provided the largest improvement in loss-exchange ratio due primarily to the following factors—

- The capability to identify and engage targets in depth

- The capability for precision engagement with on-board weapons or to provide precise target location updates for indirect fire/Beyond Line of Site (BLOS) weapons

- The capability to identify and engage targets employing camouflage, cover, concealment, deception, and denial (C3D2)

- The capability to engage targets with weapon to sensor foresight (this was particularly useful

Variable	CRP	Altitude (meters)	Speed (knots)	Signature	Weapons	ROE
Base Case	N,Y	10-350	40-100	OH-6 like	4 HF 7 PKR	Classify Recognize
Excursions	Y	100	65	RAH-66 like	2 HF 14 PKR	Recognize Identity

Legend:

CRP – Communications Relay Package

ROE – Rules of Engagement

Table 2. Unmanned Combat Armed Rotorcraft Phase "0" Study

when engaging targets under the canopy or targets employing C3D2)

- Minimal latency between target acquisition and target engagement

- The capability to perform real-time battle **damage assessment**

Unmanned Combat Armed Rotorcraft "Phase 0" Study

The objective of the "Phase 0" study was to show that an armed UAV, capable of VTOL operations, could increase the survivability, effectiveness, and responsiveness of an Objective Force maneuver unit. Specific situations from the C4ISR segment of the IBCT analysis were used to develop operational vignettes for modeling and simulation in the Advanced Tactical Combat Model (ATCOM).

MUM teams conducted Mobile Strike Operations to seek out and engage long-range weapons systems capable of influencing the Blue Force Air Assault. The strike operations were conducted to destroy key enemy artillery and command and control targets. The MUM aircraft were opposed by significant threat air defenses.

Baseline runs were conducted using only manned aircraft to complete the mission. In almost every instance, five of the six manned aircraft were lost in the effort to penetrate the air defense belt and destroy the critical targets that defined mission success. Manned systems were gradually replaced by unmanned systems. Ultimately, four of the **manned aircraft** were replaced with armed UAVs, carrying the same types of weapons. The armed UAVs were initially given the same sensors as the Tactical Unmanned Aerial Vehicle (TUAV) and the signatures of an OH–6. The Armed UAVs flew at altitudes above nap-of-the-earth, with significant exposure to enemy air defenses. The mission was accomplished with the loss of all four of the armed UAVs and occasionally one of the two manned aircraft. With the limited capabilities examined in this excursion, the armed UAV enabled the survival of 8–10 crewmen.

Subsequently, additional excursions examined signature, sensor, weapons load, and TTP changes. These changes significantly reduced attrition of the armed UAV and eliminated attrition of the manned aircraft. The emerging results are summarized as follows—

- Survivability of the armed UAV directly reduced attrition of manned systems, increased Red kills, and enabled the avoidance of loss of life

- Extremely low altitudes favored survivability but limited effectiveness of UAV sensors (smaller footprint resulting in fewer target detections) and weapons (fewer shots taken)

- Signature reduction increased survivability, which in turn increased the effectiveness of the manned-unmanned team

- Radar Cross Section (RCS) played a larger single role in survivability than other signatures due to the ability of the threat to acquire and attrit the UAV at long range

- Signature reduction in one band is not as effective as complementary reductions in multiple bands

- Weapons such as RPGs and vehicle mounted gun systems are effective components of the air defense belt even when radar and infrared (IR) based threats are rendered ineffective

- Changes in sensor performance and weapons loads on the UAV were not as dramatic at influencing overall outcomes as signature changes

- Doubling sensor performance yields an improvement in target identification and standoff capability

- Mix of precision missiles and rockets is the most effective weapons mix

- Low altitude and low airspeed provides the overall best performance

- High flying communications relay is required for networked situational awareness

- Use the manned platform as a high value Objective Force net-centric node—put UAVs in harm's way

More studies, as a follow-on set of excursions, will examine survivability characteristics in greater depth and the findings will be presented at this year's NDIA Survivability Conference.

Conclusions

As a team, MUM platforms are capable of achieving detection, classification, recognition, and identification at much greater ranges than either system could accomplish alone. The man-in-the-loop capability of the MUM team remains essential to achieve the final level of target affiliation determining the difference between friend, foe, or non-combatant, to enable precision engagement. Advanced Aided Target Recognition technology and CDAS enable quick and accurate reconnaissance of a given area. By capitalizing on the strengths of MUM elements, the manned-unmanned team increases its overall effectiveness and enables mission accomplishment. New tactics, techniques, and procedures are evolving to enable the best utilization of the MUM team in a given environment.

Based upon insights gained in the above studies, it is apparent that as designs evolve for UAVs operating within the range of enemy air defenses, consideration should be given to reducing multispectral signatures. This will result in platform survival, even at close ranges and in "pop-up target" conditions. Improved survivability enables the use of less capable (and hence less expensive) sensors, since the UAV is able to get closer to a target before being acquired. The counter-corollary is that if survival measures are cost prohibitive, then UAVs must operate outside the range of enemy air defenses. At high altitudes, sensor target identification performance and weapon performance may be significantly degraded (regardless of the cost of the sensor payload).

Ultimately, the objective of manned-unmanned teaming is to increase the effectiveness and survivability of the maneuver force as a whole. This is accomplished by prudent application of the air maneuver assets to enable our forces to ***see first, understand first, act first, and finish decisively.***

Much good work has been done through the MUM CEPs and related studies/analyses described herein. However, more focused refinement efforts, based on current findings, need to be accomplished. Clearly, from a programmatic perspective, we must determine where to optimize platforms and sensors to get the most bang for the buck. At the current level of technology and integration, and for the foreseeable future, teaming MUM vehicles (air or ground) is the appropriate path ahead. Now we must press hard on the enabling technologies that make MUM teaming most effective and efficient. Only then will we maximize the survivability of the entire objective force. ■

Major General Joseph Bergantz is the Program Executive Officer for U.S. Army Aviation. Some key assignments include Platoon Leader, 71st Aviation Command (AH); Battery Commander, A Battery, 3/35th FA; Associate Professor at West Point in the Mechanical Engineering Department; R&D Coordinator, Light Helicopter Office; APM for Longbow Apache; Product Manager for Communications Intelligence Aircraft, Commander, Aviation Technical Test Center at Fort. Rucker, AL; various Department of the Army and Office of the Secretary of Defense staff assignments; and his previous assignment as the Comanche Program Manager. MG Bergantz has a master's degree in Aerospace Engineering from Georgia Tech and a master's degree in Engineering Management from the University of Missouri (Rolla). On 31 July 2000, he was promoted to Major General and chartered as the Program Executive Officer for Aviation.

Jim Delashaw and Steve MacWillie are support contractors for PEO Aviation and CG Aviation Warfighting Center. Over the past eight years, they have been working with TRADOC Battle Labs and Directorates of Combat Developments (DCDs) to evolve air maneuver concepts. They have supported studies, analyses, experiments, and modeling and simulation efforts that are defining Manned and Unmanned Teaming (MUM) concepts and the capability MUM teaming provides Joint and Combined Arms Objective Force Operations.

Don Woodbury is the Unmanned Combat Armed Rotorcraft Program Manager at the Defense Advanced Research Projects Agency's (DARPA) Tactical Technology Office.

Tactical UAVs

The Value of Survivability Engineering

by Mr. Jim Young

With the current high level of publicity for UAV operations in Afghanistan and Iraq, one may think that UAVs have just arrived on the scene. The truth is that UAVs or drones have been used since before the Vietnam War. In fact, hostile aircraft shot down 27 U.S. AQM–84s reconnaissance drones during the Vietnam War.[1] The USN Pioneer was heavily used for targeting and reconnaissance during Operation Desert Storm, and the Predator and Hunter Advanced Concept Technology Demonstrator (ACTD) aircraft were pressed into service during the Bosnian/Kosovo conflicts. One major assumption during this period was all UAVs were built and used to be expendable. A UAV loss meant no risk of human casualties, relatively small material and value loss, and a smaller chance of resultant political fallout compared to manned aircraft.

As operations accelerated during the 1999 Bosnian/Kosovo conflict, UAVs became even more valuable for their zero casualty properties. However, these operations also exposed the susceptibilities and vulnerabilities of many UAVs. In fact, 25 NATO UAVs were lost to threat encounters causing one country to suspend their UAV reconnaissance operations[2] and others to question the maturity of their UAVs. These susceptibilities and vulnerabilities are, in many instances, the result of not including survivability engineering in the early phases of the design process. These tactical UAVs had minimum requirements and were only designed to carry a payload for a specified distance or time and return—not to survive any threat encounters! However, lack of survivability is not the only reason for lost aircraft. Losses of Pioneers and Predators, for example, can be attributed to weather, maintenance, and operator error. The specific reasons for most UAV losses still cannot be determined, as the air vehicles were not recoverable.

In spite of the inherent survivability weakness of currently deployed UAVs, battlefield commander requests for long duration real-time video links to the battlefield (and more sophisticated and expensive mission payloads) have quickly risen. Predator resources are now stretched from Southwest to Southeast Asia and the USAF has stepped up production of new air vehicles to meet demand. With this comes the realization of the tremendous value that UAVs provide the warfighter—an increased reliance for their data and other potential uses. Along with these increasing benefits came increasing concern that UAVs are not quite so expendable after all.

In assessing the expendability, and conversely the survivability, of UAVs, one must consider air vehicle cost and mission logistics. First, for tactical UAVs (from micros to Predator) air vehicle cost is relatively low in comparison to a tactical aircraft providing the same data. The cost driver becomes the payload, and sophisticated sensor payloads may be worth four or five times the air vehicle cost. This issue results in a non-expendable mission configuration (payload technology sensitivities must also be taken into account). Second, a typical UAV system consists of at least one control station and three to four air vehicles. One air vehicle loss may not jeopardize mission readiness, but two or more air vehicle losses will mean substantially reduced operational capability with limited replenishment capability. For typical UAVs operating in a hostile mission area (with no survivability features), chances of impacted operational capability are high, whether through combat losses or reduced CONOPS.

Recognizing the need to address shortfalls in existing and proposed UAV designs, engineers and program managers have more aggressively introduced survivability concepts to UAV program offices and airframe manufacturers. Just as in manned aircraft, the typical concepts of balancing survivability attributes with cost, weight, and performance are clearly recognized. With the reduced size of UAVs, pushing the envelope on technology is much more important. Most of the currently deployed aircraft have been assessed for vulnerability reduction and signature characteristics as well as platform situational awareness and countermeasures capability.

It is safe to say that most current UAVs are designed with simplicity in mind. Some have redundant wiring and multiple flight control computers. However, as there are little or no survivability requirements (remember these are expendable), there are no other vulnerability reduction features. Fuel systems are typically non-self-sealing tanks with pressure feed to the engine and no fire detection or suppression. Electrical wires are located next to fuel lines, tanks, and in fabrication convenient areas. Drive systems (engines, gearboxes, clutches, belts, and propellers) are not ballistic hardened and were not intended to be. With no survivability requirement, it would be unfair to harshly judge the airframe manufacturer; however, during this assessment it can be noted that simple design changes could reap substantial vulnerable area reductions. The JTCG/AS UAV Survivability Study (FY03) will evaluate the vulnerability of a currently deployed UAV and determine how simple changes in a specific design will cause reductions in a vulnerable area (with resultant decrease in Pk). Interfacing with the manufacturer would allow for cost/benefit analysis. The Winter 2001 issue of *Aircraft Survivability* presented basic information on ionomer fuel containment. Since that time, the JTCG/AS Vulnerability Reduction Subgroup and NAVAIR's UAV Survivability Enhancement Project (PE603216N Project W0591: Aircraft Survivability, Vulnerability, and Safety R&D Program) have funded further tests of this alternative to traditional backing boards and self-sealing fuel tanks. Preliminary results of live fire tests completed in September 2002 demonstrated very good sealing properties and hydrodynamic RAM resistance against a variety of projectiles, and offer potential lightweight sealing applications for UAVs. Specific components will be fabricated and tested in FY03.

Without the need to protect human crew and within the constraints of expendability and cost, signature reducing techniques and technologies have not been required or actively integrated into air vehicle designs. Outer mold-lines may be shaped, but untreated composite skins mean that radar cross section (RCS) characteristics will be determined by internal components. Unless designed from the start, treatments to reduce RCS, and acoustic signature may be cost and weight prohibitive, and in many instances ineffective.

The majority of tactical UAVs are equipped with electric or reciprocating gasoline engines. IR signatures are minimal on these vehicles due to low total radiated heat energy and plume, but can still be detected by the latest generation of IR threat systems. When using larger turboprop or turbo shaft engines, exhaust gases will have a definite impact on IR signature and even suppressed engines may need some form of countermeasures to counter heat-seeking missiles.

As an operator sits in his van watching video, IR, or radar data stream in, he is provided information only within his sensors' field of view. Hostile forces may track his UAV with radar and then fire guns or launch missiles. The operator may never know what hit his aircraft and have no chance to perform evasive maneuvers or employ countermeasures, as his only indication of trouble is loss of contact with the UAV. Providing the operator with additional situational awareness and simple countermeasures is paramount in order to increase the UAV's chance of survival. The solution for this is not easy. Off-the-shelf RWR/CM systems are often too heavy and may cost more than the air vehicle, instantly negating their use. A brief study that compared current RWR/CM total system weight (receivers, pre-amps, antennas, wire) to aircraft gross weight (no fuel) resulted in an average of 1.6 percent total gross weight. For a twelve hundred pound Predator, this would mean total system weight of nineteen pounds.

From this past discussion, one can see that conventional thought and off-the-shelf solutions for UAV self-protection do not exist. The JTCG/AS and NAVAIR have started to address this problem by developing and testing lightweight, low cost miniature warning and self-protection systems. NAVAIR's UAV Survivability Enhancement Program, and the JTCG/AS Project S-1-02 Miniaturized Countermeasures for UAVs are jointly leveraging funding to provide prototype warning and protection systems for potential application to all the Services' UAV programs. By starting with a premise of less than 15 pounds total weight, less than 25 watts power, and less than 40K per ship-set, concepts were developed for RF warning, RF countermeasures, and IR expendables. Three warning systems are under development and scheduled to be tested in November 2002. Several different RF countermeasure devices have been built and tested and will be integrated into a test aircraft for flight-testing in FY03. As a suitable missile warning system has not be identified for detection of vehicle IR or MANPADS systems, development has centered around pre-emptive countermeasures concepts while the UAV is in an operator defined "hostile area."

Anyone who has witnessed the take off, landing, or low altitude operations of UAVs such as Pioneer or Predator will attest to the noisiness of the engine/propeller combination. In fact, several instances of hostile detection have been attributed to a close over-flight situation where the buzzing of an engine was used to locate the UAV. Squadron commanders are especially concerned when deployed to areas where the base ingress/egress routes cannot be controlled. With a long climb to altitude, most UAVs could be very susceptible to detection. The JTCG/AS Project S-2-02 UAV Active Acoustic Cancellation will assist in solving this detection problem by developing an acoustic signature database of various UAVs, analyzing spectral and temporal content, and developing an active system to cancel out acoustic noise. This project will limit consideration to push/pull propeller aircraft such as Predator, Pioneer, and Shadow. Models such as I Can Hear It Now (ICHIN) and ARCAS (Assessment of RotorCraft by Acoustic Sensing) will be used to model the detection footprint for a variety of mission profiles. Prototype hardware will then be installed on a candidate aircraft and flight-tested to evaluate performance of the demonstration hardware and determine changes in detection range.

The JTCG/AS and the USN have recognized that now is the time to improve UAV survivability and incorporate survivability engineering. Although UAVs still are considered expendable by many, enough value has been attributed to the various UAVs currently deployed that low cost survivability improvements must be made to existing air vehicles and a correct mix of survivability engineering applied to aircraft under development. ■

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Aircraft Fire Protection Techniques

Application to UAVs

■ by Ms. Ginger Bennett

Editor's Note:

The Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) and the Service's fire protection community have been developing fire protection technologies for aircraft for a number of years. The Survivability/Vulnerability Information Analysis Center (SURVIAC) provided an excellent state-of-the-art summary of fire protection technologies in a recent issue of their SURVIAC Bulletin. *Most of these fire protection technologies have application to UAVs, so we are providing the SURVIAC summary in this issue of the* Aircraft Survivability *newsletter to make the information available to the UAV community.*

In most cases, fire is either the primary cause or a contributing factor to loss of aircraft assets in combat and noncombat situations. In many instances, injuries to personnel and loss of mission capability accompany a fire event. Aircraft fires are a significant cost to the Department of Defense (DoD). Methods and technologies to mitigate them or "design them out" are imperative, not only to save aircraft, but also to save lives and prevent property damage.

Fire prevention efforts on Military aircraft are focused on the engine nacelles (the region surrounding the exterior of the jet engine case, shrouded by an outer cover, and typically ventilated), the dry bays (which can include wing leading/trailing edges, landing gear, avionics, and weapons bays), and the fuel tanks. Historically, fuel fire and explosion have been a major cause of aircraft losses in combat. Data from Southeast Asia showed that over half of the aircraft combat losses involved fuel fire and explosions where the combustion overpressure generated exceeded the structural strength of the tank. To help address this problem, fuel tank protection systems are used on Military aircraft to protect the ullage (the void space above the fuel level in a fuel tank). Ullage can have a potentially explosive fuel-air mixture. If initiated by a combat threat, an explosion can result.

A survivability enhancement feature (either integral or retrofit) is any particular aircraft characteristic, piece of equipment, or design technique that reduces the susceptibility and/or the vulnerability of the aircraft. The goal of the survivability discipline is the early identification and successful incorporation of those survivability enhancement features that are cost-effective and allow the weapon system to accomplish its mission. Alternatively, if the loss of the aircraft is inevitable, the survivability enhancement features should allow a graceful degradation of system capabilities, giving the crew additional time to depart the hostile area.

There are three main categories of fire protection systems—passive, active, and reactive. Passive protection systems, which generally require no electronics, wiring, brackets/hardware, power, or crew interface, are activated upon the initiation of a fire event. Passive protection technologies usually only mitigate the potential for fire ignition, but do not extinguish it. If passive systems are unsatisfactory, then it may be necessary to consider an active fire suppression system. Active systems respond to the activation of a fire through the use of fire detectors. However, these systems require that the crew be notified that a fire exists and must take additional time to discharge the fire extinguisher. This valuable time could increase the damage to the aircraft. Finally, the use of reactive systems react to the initiation of an explosion and automatically discharge a substance which is intended to suppress the explosion by either physical or chemical means. Reactive systems monitor the occurrence of fire, and upon detection, release an extinguishing agent. However, reactive suppression systems can be complex and must integrate numerous subsystems. Often, there are increases in cost, weight/volume penalty, and the potential for failure/false alarms exists. As a result, some aircraft programs have been forced to forego needed fire protection and accept their fire vulnerability.

Table 1 (see page 12) shows some fire protection related survivability enhancement technologies developed in the last half century. The rest of this article is devoted to the newer technologies shown below that are currently being investigated.

Intumescent Materials

SURVIAC has been exploring the strategic placement of intumescent materials (a passive technology) within the aircraft engine nacelle for fire protection. Intumescent materials respond to the impingement of a fire by swelling and forming a protective char (coating) to physically and thermally protect the coated structure. Intumescent materials come in several different forms that include coating/paint, tape, caulk/sealant, and putty. The char thickness may range between two and 80 times that of the original material and result in an expansion amount of between one to 30 inches. The char thickness can be characterized by either high

(>15 fold), moderate (3 to 15 fold), or low (<3 fold) volume expansion. Intumescent coatings activate in a temperature range of 270 to 500°F.

The intumescent coating can be applied as a very narrow and thin strip in a form of one or more closed rings on the exterior of the engine core. These rings are positioned to swell against the enclosure at locations where clearance is minimal. If a fire occurs in an engine nacelle, the resulting flame would impinge onto a portion of the intumescent material, which upon heating would swell several orders of magnitude beyond its original thickness. This swelling would block the downstream airflow path in the vicinity of the fire, depriving it of a steady flow of oxygen and facilitating self-extinguishment (see Figure 1). If the blockage is only partial, and the flame follows the redirected airflow around the sealed-off area, the local intumescent-covered portion in that region would also swell, sealing off the perimeter of the machinery space and depriving oxygen flow until the fire self-extinguishes. In this manner, a series of "firewalls" can be formed using a minimal quantity of intumescent material. If an extinguishing system is also used, the intumescent material can improve its effectiveness, or permit smaller systems, by weakening the fire and reducing the airflow dilution of the extinguishant. Previous analysis performed by the USAF suggested feasible application for engine nacelle spaces. Intumescent materials have been used (or investigated for use) in various Military platforms for all three Services and for various commercial applications.

The intumescent coating may only be needed in a limited region of the compartment where the origin of fires is most likely. The intumescent material could also be mounted on the enclosure interior side if it is deemed beneficial. If the gap is relatively large between the engine and the enclosure, then a strip of coating may be placed on both the enclosure and engine surfaces, which upon expansion could meet in the middle.

This technique may be sufficient in many cases to permit the omission

	Engine Fire Protection	Dry Bay Fire Protection	Fuel Tank Protection
Passive	★ Intumescent material ★ Hot surface ignition mitigation	● Firewalls ● Self-healing fuel lines ● Powder packs ● Ballistic foam ★ Intumescent material ★ Simple Passive Exstinguisher (SPEX)	● Self-healing fuel tanks ● Reticulated foam ★ Ionomer self-healing fuel containment
Active	● High rate discharge fire extinguisher	● High rate discharge fire extinguisher ● Gas generator	● Venting ● Ullage inerting (inert gas) ● Tank depressurization ● Fule tank cross feed
Reactive	★ Bis(aminotetrazolyl)tetrazine (BTATZ)	★ Bis(aminotetrazolyl)tetrazine (BTATZ) ★ Reactive Powder Panels	★ Linear Fire Extinguisher (LFE) ★ Parker Hannifin Reactive Explosion Supression System (PRESS)

★ Newer Technologies

Table 1. Fire protectoin related survivability technologies

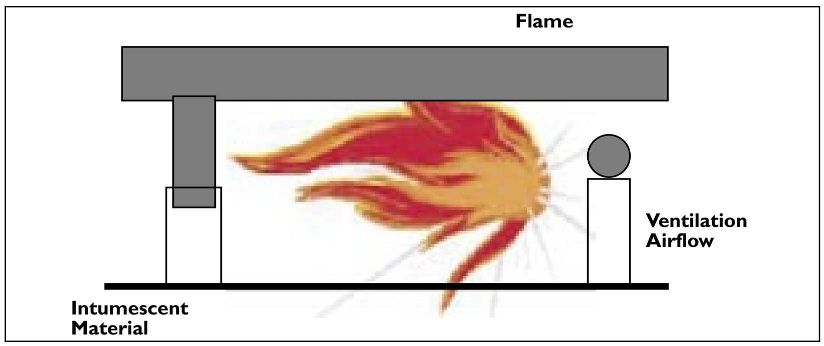


Figure 1. Flame impinges onto the intumescent material

This could prove enticing to platforms with weight/volume restrictions such as the Joint Strike Fighter and unmanned aerial vehicles. The option of fire containment/management may be better than no system.

Intumescent materials have properties that can influence their effectiveness for fire suppression (e.g., expansion factor/amount, density, protection hours, activation/maximum temperature, physical forms, char characteristics, etc). Trade-offs must be made depending upon the requirements most important to the platform. The material properties can be engineered to meet these requirements and designed around aircraft specific problems. The primary concerns are potential toxicity, fragility of char, response in a high humidity environment, installation in highly cluttered areas, and early expansion due to low activation temperature.

In a recent study, relevant intumescent data gathered included the following—

- Methods to increase char strength
- Toxicity
- Heat exposure limits
- Fragility of char
- Installation techniques
- Humidity limits
- Current applications (military and commercial)
- Suitable protected areas
- Common hazards protected against
- Expected expansion factor and resulting expansion amount based upon original thickness
- Durability of the coating
- Adhesiveness and vibration-resistance of the expanded char following activation by fire

- Physical properties of the expanded char
- Activation temperature

Current aircraft engine nacelle configuration data were obtained and used to analyze the physical and functional limitations of these intumescent materials in a notional fighter aircraft. These data included aircraft operating conditions, engine materials, and areas of minimal clearance and other dimensional data. The analyses included weight impact due to addition of intumescent material, requirements of resistance of intumescent material to airflow environment, and expected reduction in suppressant amount required due to presence of intumescent material.

This study showed the feasibility of utilizing strategic placement of intumescent materials within the ventilated aircraft engine nacelle to reduce the amount of suppressant needed. For full exploitation of this technology, an experimental program was recommended. Because of this, current efforts are underway to demonstrate and optimize the utilization of intumescent materials. Additionally, the project is investigating their use in improving the performance of extinguishing systems. The following technical issues are being addressed—

- Width of intumescent strips necessary to resist shear force of airflow while sealing
- Resistance to expansion from engine heat
- Tolerance of aircraft environment
- Total expansion heights possible to seal against surrounding structure

The project is testing and demonstrating an intumescent configuration to provide decision makers with a lower cost/weight option. The project is also developing and documenting design criteria for customers to use when utilizing intumescent materials.

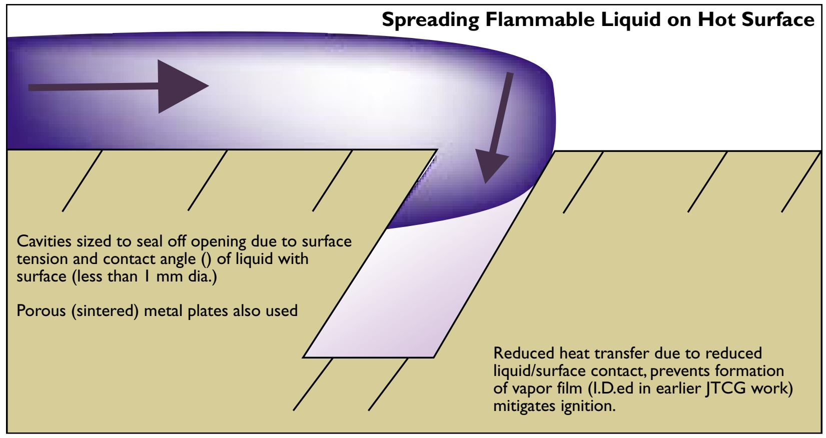


Figure 2. Surface Ignition Mitigation

Hot Surface Ignition Mitigation

The ignition of leaking fluids (from battle damage or otherwise) onto hot components (such as a bleed air duct in an engine nacelle) can be a significant contributor to fires and results in asset losses. Testing of this phenomenon has been shown to be extremely difficult to replicate consistently. In addition, existing techniques (such as the use of insulation) to mitigate hot surface ignition are heavy and costly. The preferred fire suppression approach is to keep fire from starting.

A new concept of micro-cavities (stamped, forged, rolled, or molded) on hot components to control heat transfer and boiling ignition processes is being studied and will be demonstrated on a bleed air duct. The concept will demonstrate that suspended fuel over these micro-cavities will reduce the amount of direct contact and therefore reduce heat transfer and also promote more benign forms of boiling to dissipate heat. The surface ignition mitigation concept is shown in Figure 2. The concept is practical for aircraft without fire systems, or to reduce the amount of extinguishant required. Current efforts underway are identifying parameters that dictate the conditions suitable for ignition on a hot surface and optimizing surface micro-cavity configuration to increase a safe operating temperature range. These efforts will deliver a protocol to predict hot surface ignition temperature based on the operating conditions and demonstrate a component surface treatment to mitigate ignition.

BTATZ

The Los Alamos National Laboratory discovered a new rocket propellant—Bis(aminotetrazolyl)tetrazine (BTATZ). It is a nonexplosive, nonpyrotechic, inflammable solid that decomposes rapidly without flame (low temperature gas) and produces nitrogen. This nitrogen production is highly efficient with 90 percent of the propellant converted to gas. BTATZ is impact insensitive and does not react immediately. Because of this, BTATZ has been identified as a composition highly suitable for fire suppression applications.

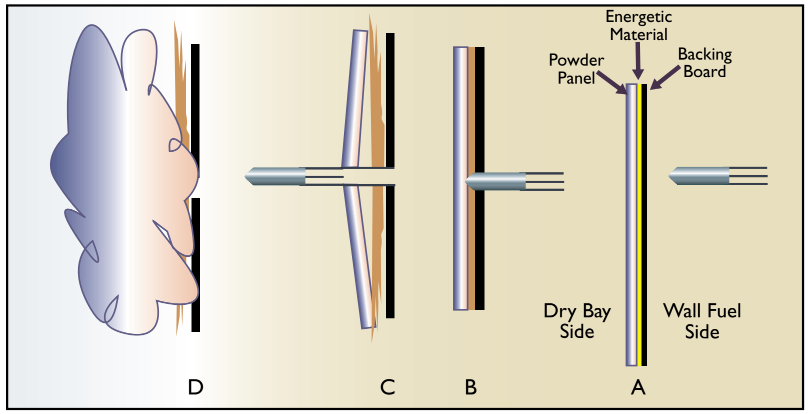
The potential for its use provides possibilities of entirely new "outside of the box" fire suppression systems. The properties of BTATZ suggest that system simplification and lightweight packaging are possible. This could be accomplished using vacuum packed molded bricks, powder packs, or conceivably even no packaging (with the use of propellant paint, etc.). The propellant would be installed in dry bays near fire prone regions. Heat from the dry bay fire results in the propellant activation and fire extinguishment.

BTATZ is a relatively new composition. Several issues need to be resolved before applying it in "real world" situations. The effluent may be toxic with the potential for the production of hydrogen cyanide since it contains carbon, nitrogen, and hydrogen. The impact of the hydrogen production—the quantity, flammability characteristics, and ability to be reduced—needs to be examined. Other issues include long term stability (shelf life) and sensitivity to initiation from static sparks.

Current NAVAIR work is underway to address the BTATZ issues. Work currently sponsored by the DDR&E Next Generation Fire Suppression Program (NGP) is investigating propellant "scale-up" production methods, effluent analysis and species measurement, and chemical suppression enhancement/additives. Additional work currently sponsored by the JTCG/AS is investigating application of BTATZ as a powder pack enhancement and further development of BTATZ "paint." Additional work was co-sponsored by V–22 research and development to investigate the powder pack enhancement (with the use of BTATZ), to include a conductive binder (to reduce static sensitivity), to produce test quantities of the propellant, and to demonstrate the concept in a full scale aircraft fire scenario. BTATZ will also be investigated for its ability to withstand the aircraft engine nacelle environment.

Reactive Powder Panels

Current powder pack technology includes a lightweight, brittle, honeycombed panel filled with a fire suppressant powder (usually aluminum oxide). The panel is normally affixed to a dry bay wall adjacent to a fuel tank. Projectile damage to a powder pack results in release of some powder into the dry bay to prevent ignition of leaking fuel. However, some limitations exist with this current design. Fire suppressant powder is dispersed solely through kinetic energy transfer from the projectile to the powder panel. The amount of dispersed powder is limited to the region of projectile penetration. Most of the suppressant can remain encased within the powder panel, unused and "wasted." Fuel and incendiary dispersion can be much more extensive than the powder dispersion. The application of powder packs must then usually be restricted to smaller dry bays, with little or no airflow. Usually, additional passive technologies (such as self-sealing fuel cells) are combined with the powder packs to achieve a more effective protection level. This results in increases in cost and weight penalties.



A.) Small amount of impact sensitive pyrotechnic is thinly painted on surface of supporting backing panel. Powder panel is affixed on top of this painted surface.

B.) Round impact results in initiation of pyrotechnic.

C.) Pyrotechnic activation results in removal, breakup, and discharge of "entire" powder panel from wall.

Figure 3. Reactive Powder Panel Enhancement Concept

The Naval Air Systems Command (NAWCWD, China Lake) has recently demonstrated two [reactive (see Figure 3) and enhanced] alternative technologies that provide dramatic improvement over current fire protection powder panels. The reactive powder panels are commercial powder panels with reactive energetic backing, developed under sponsorship of JTCG/AS. The enhanced powder panels are totally redesigned powder panels [developed under sponsorship of DDR&E Next Generation Fire Suppression Technology Program (NGP)].

The reactive powder design incorporates a small amount of impact sensitive pyrotechnic (BTATZ) thinly painted on the surface of the panel. The powder panel is then affixed on top of this painted surface. When a round impacts the panel, the pyrotechnic is initiated and results in removal, breakup, and discharge of the entire powder panel from the wall. Pyrotechnic gases effectively disperse the fire suppressant powder.

To be effective, BTATZ must be initiated by bullet impact almost simultaneously along its entire surface. However, BTATZ is impact insensitive and does not react immediately. To solve this problem, a dual layer of BTATZ and an additional impact sensitive initiator material can be sandwiched between the powder panel and the dry bay wall. This energetic initiator activates on impact and initiates the entire surface of the BTATZ. The initiator also provides some added energy to assist in the break-up (crack) of the powder panel. The energetic initiator must be applied as a very thin sheet or paint, be sensitive enough to be initiated by the projectile (fragment) impact, and rapidly react to initiate the BTATZ main propellant charge along the majority of its surface. The energetic initiator should provide some energy to assist in shattering the powder panel, but must not be overly energetic to result in damage to the supporting aircraft structure or result in severe injury from accidental activation. Also, the energetic initiator should create only a minimal, low-temperature, flame (if any).

Baseline powder panel tests were performed for comparison to the reactive and enhanced powder panel designs. This testing included demonstration testing of the concept versus actual dry bay simulator fires. Both the reactive and enhanced powder panels showed dramatic improvement in fire protection performance over standard commercial panels. There was significantly greater powder discharge with the reactive/enhanced (90 percent) over the standard (5 percent). There was much greater powder dispersion throughout the entire dry bay. Effectively both are flooding agents providing passive fire suppression verses ignition mitigation as with the standard powder panels.

Simple Passive Extinguisher (SPEX)

The SPEX concept focuses on fire protection system simplification with minimal, or no supporting subsystems. An ideal application of the SPEX concept would simply place an agent (such as BTATZ) within the volume to be protected. The agent would be reactive and sensitive to the characteristics of a fire (heat, smoke, and potentially light). Exposure to the fire would result in agent activation to extinguish the fire.

Commercial-off-the-shelf (COTS) fire suppression agents may be applied to the SPEX concept. Several fire suppression vendors have products already designed to utilize heat as a primary (not backup) activation mechanism. COTS technologies can be applied to SPEX at the simplest system level—heat reactive fire bottles, and pyrotechnic suppressors with heat sensitive initiators. System retrofit would merely involve installing SPEX fire suppression canisters or bottles near fire-prone regions. These kits could be installed at the squadron maintenance level. Heat from the fire would result in the discharge of agent and fire extinguishment.

Dry bay clutter (obstructions), geometry, or internal airflow may require some modification of SPEX to include a heat sensitive initiator "fuze" that would expand the fire detection coverage area and activate a multiple SPEX packet. An ideal fuze material would be quick reacting and flameless (potentially BTATZ).

Assuming the benefits (due to lack of detector, activation hardware) of the SPEX/BTATZ concept, the fire suppression system could be approximately one-sixth the weight of an equivalent active system. Since the SPEX/BTATZ concept has not been commercially produced to date, the cost benefits are unknown but should be similar. Using a SPEX/BTATZ concept with a chemical suppression additive could result in a synergistic enhancement. The fire suppression system could be approximately one-twelfth the weight of an equivalent active system.

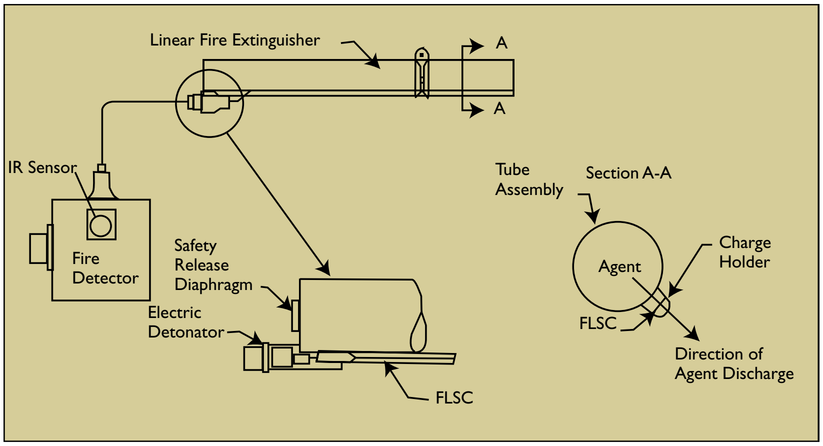


Figure 4. Linear Fire Extinguisher (LFE)

The SPEX concept can be applied now with commercially available technologies, and emerging technologies promise even greater system simplification to enhance SPEX benefits.

Linear Fire Extinguisher (LFE)

Projectile-induced ullage explosions are usually generated by a specific sequence of events. The elapsed time from ballistic impact to a fully developed explosion occurs within milliseconds. The LFE system, initiated by detection of projectile function or fragment impact flash, operates within the same millisecond time frame and is expected to create a "protected" ullage space before damaging overpressures are developed from the ensuing explosion. The parallel explosion-development/system-activation sequence is as follows—

1. Projectile penetration causes an incendiary flash and the subsequent detonation disperses incandescent particles and fragments within the threatened fuel tank, beginning the process of explosion development.
2. Optical sensors respond to the incendiary flash, triggering a detonator to activate the extinguisher(s).
3. The extinguisher(s) discharges an explosion inhibiting agent that suppresses the explosion, thus negating development of damaging overpressures.

The LFE system consists of an optical sensor, a hollow thin-wall stainless steel tube for extinguishant storage, and a combination detonator and flexible linear shaped charge (FLSC) mounted over the exterior of the tube for extinguishant discharge initiation (see Figure 4).

An active explosion suppression system is feasible, but dependent on the suppression agent used. Some of the extinguishing agents tested include—

- Distilled water
- Aqueous film-forming foam (AFFF) and water solution
- Water, AFFF, and Halon 1301
- Water and monoammonium phosphate powder
- 30 percent calcium chloride and water solution
- 50 percent ethylene glycol and water solution
- 70 percent ethyl alcohol and water solution
- Halon 1301 and water mixture
- Propane
- Monoammonium phosphate powder mixed with Halon 1301

- FC–218
- HFC–227ea
- HFC–125
- Pentane

Some advantages of the LFE system include speed (response within five milliseconds), suppressant speed (1000 ft/sec), detectors, one channel IR fiber optic, efficient distribution, and low weight (mostly suppressant).

Some disadvantages of the LFE system include—power consumption, detector technology lags, ullage overpressure with halon, and reaction forces from tube.

The following items must be addressed—

- Compatibility of the suppressant with the environment and the fuels requiring protecting, especially considering alternative suppressants
- Reactive loads that are imposed on the aircraft structure when the LFE is discharged.
- Installation and operation issues of the finalized system
- Concerns of overpressures must be addressed. Pyrotechnic devices in aircraft fuel tanks also present a potential risk to the aircraft
- Effects of discharging the LFE when completely submerged in fuel, and the ability of successfully dispersing the agent into the fueled areas

Discussions with Government personnel indicate that a LFE test program is scheduled to be performed at Wright-Patterson AFB, Ohio. The test program will not only address the LFE, but will also attempt to quantify the previously described reactive loads, if possible. In later studies, methods to mitigate these loads will be explored.

Parker Hannifin Reactive Explosion Suppression System (PRESS)

The Parker Reactive Explosion Suppression System (PRESS) is designed to be installed in aircraft fuel tanks and react to and suppress fuel tank explosions. It consists of an optical detector, transmission lines, and a suppression tubes) containing a water/brine solution. This system is designed to respond within a few milliseconds to engage the flame front and reduce pressures below damage causing levels. After detection, the transmission lines transmit a signal to the suppression tube, which initiates an exploding bridgewire circuit. This, in turn, initiates a detonating cord and propellant internal tube, creating a high pressure expulsion force to expel the adjacent bladder filled with water. The water exits through orifice holes, is transmitted through radial channels in the external nozzles, and released as five-micron-thick sheets. These sheets break up into ten-micron droplets which absorb thermal energy released by the explosion. This process occurs in its entirety within a few milliseconds.

Some advantages of the PRESS system include fastest responding system—allows less suppressant, lighter weight, system designed for liquids like water, tank overpressure problem not evident, and nozzles allow directed flow of suppressant.

Some disadvantages of the PRESS system include its requirements for large scale proof-of-concept testing, more complex system—chance for malfunction despite high reliability components, and possible expense in manufacture.

The following items must be addressed—

- Use of explosives and chemical propellants inside fuel tanks to suppress a fuel explosion
- Introducing water into a fuel system
- Introducing a chloride brine into a fuel system
- Ultra-fast suppressant dispersion raises concerns about mounting bracket reaction loads
- Resistance to battle damage
- Discharge of suppressant when the dispersion tube is submerged in fuel (potential of producing a hydraulic ram effect)
- Installation of the PRESS system in small cluttered compartments would be difficult and costly; also detection would be difficult since the detectors are typically line of sight

Discussions with Government personnel indicate that technical complications prohibited demonstrating the effectiveness of PRESS for suppressions of fuel vapor explosions. These discussions indicated that the PRESS nozzle design was too complex and required very tight tolerances (which prohibited a low cost manufacture). To alleviate this problem, conventional nozzles were used in a radial fashion to generate the same effect.

Parker Hannifin representatives stated that the PRESS technology has been shelved due to technical and funding issues. The technical issues included the nozzle technology development. Several different approaches were attempted. In their opinion, nozzle technology has not advanced to a state that would allow the PRESS technology to be further pursued by Parker Hannifin.

Ionomer Self-healing Fuel Containment

The ionic forces in ionomer plastics provide a “self healing” capability. When these forces are destroyed at impact, they instantly reform in a similar manner as when a bullet passes through water. This lends itself to fluid (fuel, oil, hydraulic) containment applications.

An ionomer is an ion-containing polymer. Such a thermoplastic resin has ionic bonds between the polymer chains. Ionic crosslinks occur randomly between the long-chain molecules. Typical properties of ionomers include—

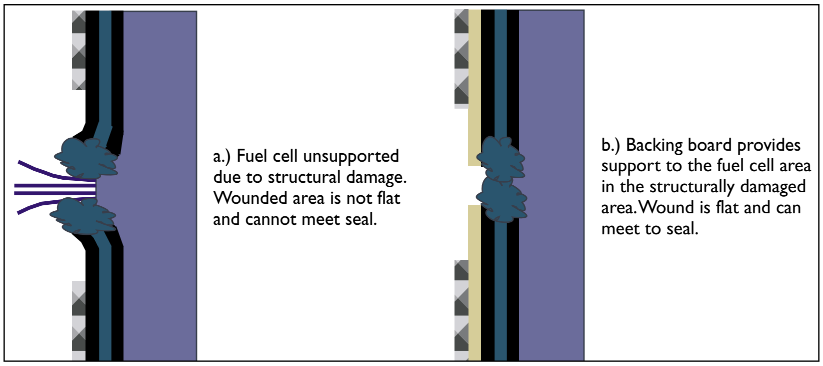


Figure 5. Ionomer self-healing fuel containment fuel cell backing board

- High impact strength at low temperatures
- Puncture and abrasion resistance
- High melt elasticity
- Good thermoforming properties
- Low sealing temperatures
- High sealing seam strength
- Resistance to grease, oil, and solvents

Current materials used in "self-sealing" backing boards adjacent to fuel tanks incur some damage (a "hole") after a ballistic impact (see Figure 5.). This may allow fuel leakage into the dry bay through this hole. An ionomer backing board would be expected to "self-heal" after impact, and may thereby provide additional containment of fuel from a wounded self-sealing fuel cell. This may provide for expanded applications including backing board fuel containment of nonself-sealing fuel cells, or self-healing ionomer fuel cells. Other potential applications include self-healing fuel lines, self-healing hydraulics containment covers/linings, and self-healing gearbox oil containment covers/linings.

The objective of this effort is to develop and demonstrate a simple and low-cost alternative/enhancement to current self-sealing fuel cell technologies. Commercially available ionomers (properties, types, and suppliers) are being investigated, materials are being acquired, the ballistic response and containment are being tested and the analysis and results are being documented.

Recent events have demonstrated the need for cockpit hardening of aircraft. The high impact strength of ionomers also suggests possible applications in cockpit hardening. Should time and funding permit, additional testing may be conducted to evaluate ionomer's resistance to bullet impact as a function of its thickness and layers.

Most of these fire protection technologies are light weight, effective, and can be applied to UAVs. If you are interested in finding out more about any of these technologies, contact the author and she will help you get the information you need or put you in contact with the JTCG/AS Fire Protection Project Engineer for more detailed information. ■

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- *Joseph A. Manchor, NAWCWD, China Lake*
- *Richard B. Mueller, NAWCWD, China Lake*
- *Mike Bennett, 46th Test Wing, WPAFB*

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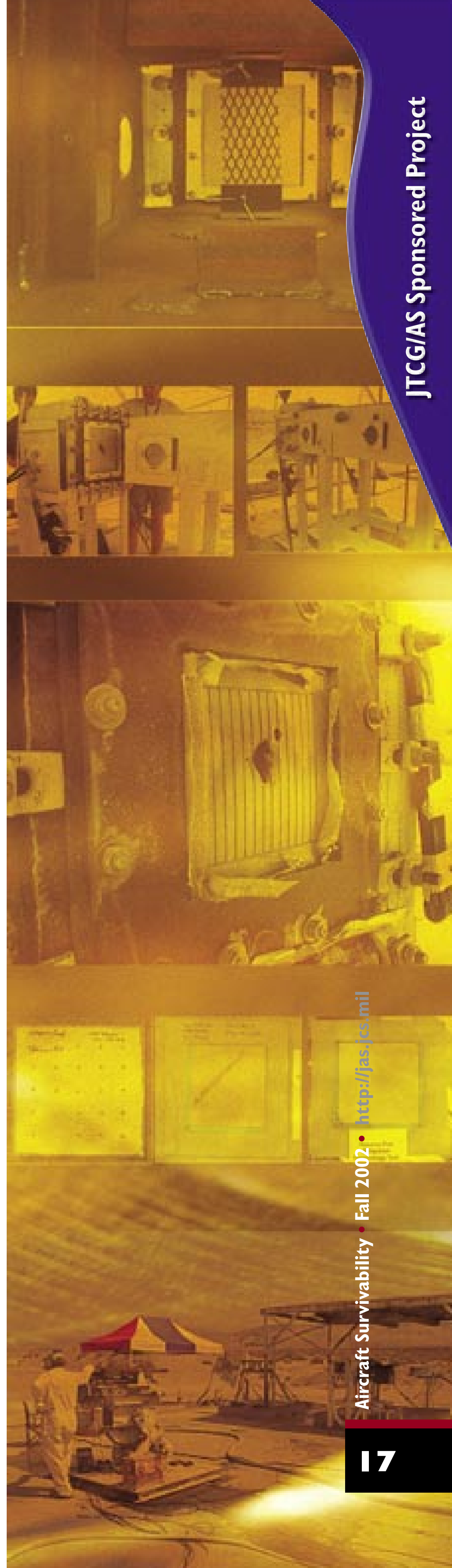

Joint Live Fire/Air Program (JLF/Air)

FY03 Program Build

■ by Mr. Jeffrey Wuich and Mr. Tracy Sheppard

The Joint Live Fire (JLF) Program was initiated by the Office of the Secretary of Defense (OSD) in March of 1984 to establish a formal process to test and evaluate fielded U.S. systems against realistic threats. The program continues today under the auspices of the Deputy Director, Operational Test and Evaluation/ Live Fire Testing (DDOT&E/LFT). The JLF Program was chartered to assess the vulnerability of fielded U.S. armored vehicles and combat aircraft to threats likely to be encountered in combat and to evaluate the lethality of fielded U.S. munitions against realistic targets. The Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) and the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) are the executive agents for the JLF Program, aircraft and ground/mobile systems, respectively, while the Services execute and support the tests under joint leadership. The JLF Program consists of three groups: Aircraft Systems (JLF/AS), Armor/Anti-Armor (JLF/A/AA), and Sea Systems (JLF/SS). JLF/AS focuses on the vulnerability of U.S. fixed-wing and rotary aircraft to realistic threats and on the lethality of fielded U.S. weapons/munitions against foreign aircraft. This article features JLF/AS projects receiving FY03 funding.

The DDOT&E/LFT intends to more closely integrate the JLF Program into other focus areas within DOT&E, such as integrated survivability assessments and increased understanding of vulnerabilities of legacy systems; and to leverage the program with other DOT&E investment programs (Threat Systems Office, JTCGs, Center for Countermeasures, and Live Fire Testing and Training Initiative). To that end, the DDOT&E/LFT has approved JLF/AS projects for FY03 that will provide empirical data on the vulnerabilities of some of our currently fielded aircraft platforms. These data will be made available to the test and evaluation community at large and to the system program managers. The FY03 JLF/AS Program consists of vulnerability tests and assessments on the following fielded rotorcraft and fixed-wing aircraft: the AH–1, CH–47D, CH–53E, and the H–60.

AH–1 Testing

As we have seen in recent armed conflict, our front-line helicopter systems are susceptible and vulnerable to attack from readily available threats. Two threats of primary interest to the vulnerability test and evaluation community are the rocket propelled grenade (RPG) and the man-portable air defense systems (MANPADS) family of shoulder launched, air-defense missiles. The JLF/AS FY03 Program will investigate the vulnerability of the AH–1 front-line attack helicopter to these threats. The goal of these two efforts is to identify potential survivability enhancements for this and other helicopter platforms.

In FY03, JLF/AS will begin a tri-service (Army, Navy, and Air Force), multi-year investigation of the vulnerability of helicopters (represented by the AH–1) to rocket propelled grenades (RPGs). This effort represents the first empirical vulnerability investigation of helicopters to this threat. This effort will provide information to aid combat mission planning, increase aircraft/aircrew survival in combat, aid battle damage assessment repair training, and provide vulnerability reduction recommendations. The Army test component will be conducted in FY03 at the facilities of the Survivability/Lethality Analysis Directorate (SLAD) of the Army Research Laboratory (ARL) at Aberdeen Proving Ground, Maryland. These tests, employing plate arrays and actual helicopter structures as targets, will examine "first-contact" impact parameters including fuze sensitivity, structure penetration, and (combined) damage mechanisms. The Navy test component will be conducted in FY03 at the facilities of the Weapons Survivability Laboratory of the Naval Air Warfare Center Weapons Division (NAWCWD) at China Lake, California. These tests will investigate the self-destruct "air-burst" RPG against an arena of plates followed by tests against an AH–1S to gather data and compare damage mechanisms (e.g., damage created by " air-burst" encounter compared to damage created by "first-contact" encounter). The RPG project will culminate in FY04 at the 46th Test Wing facilities, Eglin AFB, Florida with ballistic events against a full-up, operational, instrumented AH–1 helicopter. Quick-look reports will be prepared upon completion of testing by each Service. A single, final report will be prepared in FY05 that will include combined analysis of RPG lethality and AH–1 vulnerability to "first-contact" and "air-burst" fuzing. The ARL project engineer for this effort is Mr. Steve Polyak, the NAWCWD project engineer is Mr. Hau Nguyen and the 46 OG/OGM/ OL–AC project engineer is Mr. Pat O'Connell.

The vulnerability of helicopters to MANPADS will be investigated in a two-year, joint Service vulnerability investigation (Army and Air Force). The vulnerability community views this threat as perhaps the most lethal against helicopters fielded today. Similar to the RPG effort, this effort will provide information to aid combat mission planning, increase aircraft/aircrew survival in combat, aid battle damage assessment repair training, and provide vulnerability reduction recommendations. In keeping with the DDOT&E/LFT's desire to more closely integrate the JLF program to other DOT&E investment programs, this project is a follow-on effort to a JTCG/AS test investigating a potential survivability improvement. The JTCG/AS project is investigating the survivability enhancement afforded by moving the threat missile's aimpoint through an alternative infrared source. It is believed that by moving the aimpoint to a less vulnerable area of the platform, or moving the aimpoint off of the platform altogether, a significant increase in survivability can be achieved at a relative inexpensive and easily configured (field expedient) process. Two tests will be performed at Eglin AFB, Florida in June of 2003. For the first event, the AH–1 target platform will be equipped with the JTCG/AS developed device to move the threat missile's aimpoint. This event will demonstrate the effectiveness of the device in moving the missile's aimpoint and will provide vulnerability information on the helicopter for such an encounter. The second event will examine the susceptibility and vulnerability of the baseline platform (no survivability enhancements). A final report will be prepared in FY04 that will include combined analysis of MANPADS lethality and AH–1 vulnerability to the MANPADS threat. The ARL project engineer for this effort is Mr. Steve Polyak and the 46 OG/OGM/OL–AC project engineer is Mr. Greg Czarnecki.

CH–47 Testing

In FY03, ARL will complete a multi-year JLF/AS effort to investigate the tolerance of the Chinook helicopter's composite rotor to ballistic damage. This effort was coordinated directly with the Office of the Deputy Undersecretary of the Army (Operations Research) and the Army CH-47 program manager and leverages and supplements the ongoing CH-47 Live Fire Test and Evaluation program. This effort is being conducted at ARL/SLAD facilities at Aberdeen Proving Ground, Maryland. This final phase of the project will consist of shots into operating rotor blades on a full-scale CH–47D ground test helicopter. These tests will provide component through system-level response data that will be coupled with engineering analyses to determine the effects of blade damage on helicopter performance and crew function. This effort will also provide information to aid combat mission planning, increase aircraft/aircrew survival in combat, aid battle damage assessment repair training, and provide recommendations for more survivable helicopter rotor blades. Prior phases in FY99 through FY01 achieved the first-ever ballistic vulnerability tests involving this blade and post-ballistic engineering analysis-test support from the manufacturer, Boeing Helicopter. The overall results are applicable to two fielded Army –47 models (i.e., D and E; the latter is a special operations aircraft that has seen extensive combat use in Afghanistan) and the future production F model. ARL will deliver a detailed test plan, a pre-shot prediction report, and a detailed test report for each test phase. The ARL project engineer for Phase III is Mr. Patrick Swoboda.

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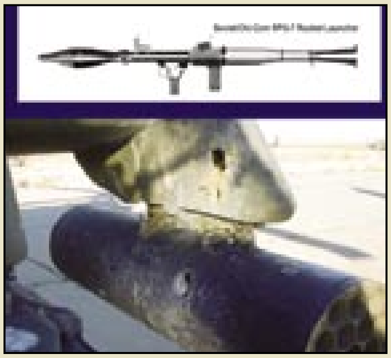

Figure 1. AH–1 Vulnerability to Rocket Propelled Grenades

Figure 2. AH–1 Vulnerability to MANPADS

Figure 3. Chinook Rotor Blade Ballistic Vulnerability Tests—Phase III Dynamic

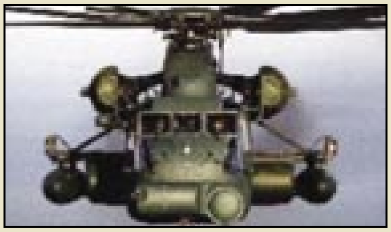

Figure 4. CH–53 Vulnerability to small arms/autmatic weapons (SA/AW) and anti-aircraft artillery (AAA)

Dennis S. Lindell

Young Engineers in Survivability

by Mr. Lex Morrissey

The Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) is pleased to recognize Mr. Dennis Lindell as our third Young Engineer in Survivability. Dennis is one of the bright young engineers at the U.S. Army Research Laboratory (ARL), Survivability/Lethality Directorate (SLAD), who is doing an excellent job supporting JTCG/AS, Joint Live Fire (JLF), Live Fire Test & Evaluation (LFT&E), and Army Vulnerability/Lethality (V/L) Research and Development (R&D) Programs.

After graduating from the University of Minnesota in 1988 with a Bachelor of Science Degree in Aerospace Engineering and Mechanics, Dennis came to work for the U.S. Army Ballistic Research Laboratory (later absorbed into ARL) in the Vulnerability/Lethality Division, Air System Branch, at Aberdeen Proving Ground (APG), Maryland. Among his initial assignments, he worked with a senior aeronautical engineer to develop a physics-based model to compute helicopter flight dynamics with engine power loss due to combat damage. The resulting model is now a standard analysis tool used in the SLAD, providing much improved accuracy for U.S. Army helicopter ballistic vulnerability assessments. Further applying his engineering skills and gaining additional assessment experience, Dennis became responsible for developing input data on helicopter structures and mechanical-hydraulic flight controls for ballistic vulnerability assessment codes (e.g., COVART and later MUVES/S2). He also became proficient in the use of BRL–CAD for creating computerized target descriptions, rendering several highly detailed descriptions of U.S. Army and threat aviation systems.

In 1990, Dennis began service as a JLF Air project engineer. His first assignment was the UH–60A Black Hawk tail structures ballistic vulnerability test, followed by the AH–-64A Apache tail structures test. Significant among his contributions was the design of apparatus to load the target structures (tail booms and vertical stabilizers) during shot events and thereafter to determine post-damage structural performance. Those JLF test data have been extensively used for vulnerability assessments of first model Black Hawk and Apache helicopters and subsequent product improvement and special operations variants (e.g., the MH–60K and AH–64D). Continuing his JLF involvement, Dennis is currently project engineer for the CH–47D Chinook power train ballistic vulnerability tests. These tests will provide the first empirical data on the ballistic toughness of the CH–47D's rotor transmissions.

Capitalizing on his strong interest and growing involvement in vulnerability testing, Dennis was chosen as technical lead to select, procure, and bring to operational capability the first integrated digital system for process control and data acquisition-processing at SLAD's Vulnerability/Lethality Experimental Facility at Airbase Site 6 at APG. This system, enabled with Hewlett-Packard computers and instruments, provided significant advancements in capability and operating efficiency at the facility. The system, managed by Dennis to keep pace with technology advancements and new program requirements, has been a key component in numerous JLF and live fire tests and U.S. Army Vulnerability/Lethality research experiments.

In 1995, Dennis was named lead project engineer for AH–64D Apache Longbow Mast Mounted Assembly (MMA) live fire testing. This was the U.S. Army's first aviation system LFT&E program and the first-ever ballistic vulnerability test involving helicopter mast-mounted radar. Managing a complex two-phase (subsystem and system level) test program under a compressed U.S. Army development schedule, he was responsible for planning and conducting the test, preparing and maintaining test material (including a full-up operational AH–64 ground test vehicle), damage assessing, and test reporting. He designed a unique loading fixture to impart simulated aerodynamic and vibration loads to the MMA for making pre- and post-ballistic damage strain and displacement measurements. He presented the test results in a series of high-level briefings to the Apache LFT&E working group, the Advanced Attack Helicopter Program Manager, and the Office of the Secretary of Defense (OSD) (DOT&E /LFT&E). Successful execution of this test program filled a critical ballistic vulnerability data void and met the system's milestone IIIA requirement for LFT&E.

In 1996 when the JLF dynamic helicopter main rotor blade ballistic impact test with a full-up AH–1 helicopter was planned, preshot damage predictions were required by the test sponsor. In response to this need, Dennis developed a new methodology to predict rotor blade ballistic damage by geometrically modeling (with BRL–CAD) the blade and the threat damage mechanisms (penetration, fragmentation, HE blast) and applying Boolean logic to produce three-dimensional computer images of damaged rotor blades. He used the methodology to prepare detailed pictorial and quantitative physical damage estimates for each test event and later compared the predictions with the test results to assess prediction accuracy and identify methodology improvements. This high-visibility effort was ultimately briefed at the OSD level and is documented in a JLF report. Dennis also presented papers on his work at the XXXVI Annual U.S. Army Operations Research Symposium and the 1997 National Defense Industrial Association Live Fire Test and Evaluation Conference.

In 1997, Dennis Lindell was selected as SLAD's System Leader for the U.S. Army Chinook helicopter. In this position, he is responsible for planning and coordinating the complete SLAD survivability program supporting this system for all threats to include ballistic, directed energy, and nuclear, biological, and chemical (NBC). Dennis also leads SLAD's ongoing test and analysis effort for the CH–47F Live Fire Test Program, and he is the test engineer for the cockpit structures and the fuel subsystems Live Fire tests. He authored an article on this subject, CH–47F Chinook (Improved Cargo Helicopter) Live Fire Test and Evaluation, for the JTCG/AS Aircraft Survivability Newsletter, Summer 2000 issue.

In 1999, the CH–47D helicopter auxiliary power unit (APU) experienced several catastrophic compressor non-containment failures that endangered personnel and led to the grounding of a major portion of the U.S. Army's Chinook fleet. Working with the Cargo Helicopter Program Managers Office, Dennis led an experimental team that down-selected and qualified an effective barrier material to contain a worst-case compressor wheel failure. The timely, successful conduct of these experiments leading to a containment barrier retrofit allowed the U.S. Army's CH–47D fleet to return to full operational readiness months sooner than would otherwise have been possible.

In 2000, Dennis was appointed SLAD's Aviation Mission Area Coordinator. In this position he directs the planning and conduct of the Directorate's total aviation mission program for all survivability disciplines: ballistic; directed energy and electronic warfare; signatures; information warfare; and nuclear, chemical, and biological. Annually, this is a $5M program representing approximately 30 staff years of technical work involving all major U.S. Army aviation platforms.

Mr. Lindell serves as the U.S. Army co-chair on the JTCG/AS Vulnerability Reduction Subgroup Flight Controls Committee. He has authored more than 20 ARL and JLF technical reports and is a frequent presenter at survivability symposiums and conferences. Last year, he was recognized as one of "Ten Outstanding AMC Personnel of the Year for 2001," receiving this award in a special ceremony from Dr. Robert Whalin, Director of ARL.

In his leisure time, Dennis enjoys the outdoors and its challenges. He is an avid rock and ice climber and enjoys camping and off-road biking. He recently took up the sport of kayaking. He also enjoys traveling (most recently to Italy) and photography. It is with great pleasure that we present Mr. Dennis Lindell as the latest JTCG/AS Young Engineer in Survivability. ■

Mr. Lex Morissey has a B.A. Degree in Physics from Loyola College 1962. He came to work for the Army in 1963 at Nuclear Defense Laboratory (NDL). He then went to Ballistic Research Laboratory where he worked with directed energy weapons. In 1988, he started on the Dome Street program and has been associated with the JLF Ground since that time. Mr. Morissey went to ARL in 1992 where he was the mission area coordinator for air defense and then in 1998 returned to ballistic work as the branch chief of the Experimental Design, Conduct, and Analysis Branch.

Figure 1. (page 20 top left) Dennis Lindell receiving 2001 AMC Top Ten Award from Dr. Whalin, Director of ARL

Figure 2. CH–47F LFT&E: Fuel subsystem hydrodynamic ram test

Figure 3. CH–47D Chinook Helicopter APU Shield R&D Project

Figure 4. Chinook GTV for LFT&E Test Series

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CH–53 Testing

In a multi-year investigation of the vulnerability of the CH–53E, the JLF/AS program will conduct and assess damage from ballistic impacts to the platform. Threat munitions to be used during this effort include small arms/automatic weapons (SA/AW 12.7 mm API and 14.5mm API) and include anti-aircraft artillery (AAA - 23mm API & 23mm HEI). In addition to the aforementioned benefits of conducting this type of effort, this project will also verify/validate the 1979 CH–53E Vulnerability Assessment. The first year of this effort (FY03) will concentrate on test planning and asset acquisition. In FY04, dynamic ballistic tests will be conducted against CH–53E rotor and drive subsystems (main and tail rotor blades, pylon fold, tail drive shaft) under representative dynamic loads. These tests will be used to gather damage data and perform post-damage operating endurance testing on dynamic components to evaluate the reduction or loss of dynamic flight load capability. In FY05, ballistic tests will be conducted against CH–53E fuel systems and dry bays. These tests will be used to assess the vulnerability of the CH–53E to ballistic threat-induced structural removal/damage as a result of ullage explosion and/or dry bay fire. Ballistic testing will be conducted at the NAWCWD facilities at China Lake, California. A final report will be prepared in FY05. The Navy's project engineer for this effort is Mr. Joe Manchor.

H–60 Testing

Three H–60 efforts are funded under the FY03 program. Two of the efforts will investigate the vulnerability of major platform components to ballistic impacts: the tail rotor subsystem and the transmission. The third effort will investigate the effectiveness of the H–60's engine nacelle fire extinguishing system.

The ARL will complete a two-year effort investigating the tolerance of the Black Hawk helicopter's tail rotor assembly (blade and hub) to ballistic damage. The rotor blade is a graphite and fiberglass composite construction, and the hub features composite and metallic components. The program is being conducted at ARL/SLAD facilities at Aberdeen Proving Ground, Maryland. Under Phase I of the program funded in FY02, blades and hub parts will be shot statically to examine damage forms and extent. Various threat armor piercing and high explosive projectiles will be investigated. In FY03, guided by the Phase I test results, select components will be shot under flight-representative powered operating conditions on a subsystem test rig. The rig was designed and built from actual H–60 parts by ARL/SLAD and Army Aviation Logistics School personnel. The results of this project will be applicable to several fielded Army -60 models (i.e., A, L and K; the latter is a special operations aircraft) and the future production M model. ARL will deliver a detailed test plan, a pre-shot prediction report, and a detailed test report. The ARL project engineer for this effort is Mr. Fred Marsh.

In FY03, ARL will also initiate an effort to investigate the "run-dry" tolerance of the improved durability gearbox (transmission) located on the Black Hawk to ballistic damage. A detailed test plan, pre-shot predictions and acquisition of additional H–60 hardware will be completed in FY03. Ballistic vulnerability tests will be conducted in FY04. As for the tail rotor effort, this effort will provide information to aid combat mission planning, increase aircraft/aircrew survival in combat, aid battle damage assessment repair training, and provide vulnerability reduction recommendations. Likewise, results will be applicable to several fielded Army -60 models. The ARL project engineer for this effort is Mr. Fred Marsh.

A joint Navy and Air Force project was initiated in FY02 to conduct parametric controlled damage and ballistic tests to evaluate the influence of varied damage levels to the effectiveness of the current H–60 aircraft engine nacelle fire suppression system with current and alternative fire suppression agents. The main issues are—

1. Halon 1301 engine nacelle fire suppression systems are not designed to account for the changing conditions that are incurred as a result of combat damage. Ballistic damage may alter the conditions within an engine nacelle so as to hinder the protection afforded by these systems, and;

2. Halon 1301 environmental issues have resulted in some aircraft programs transitioning to alternative fire suppression agents and systems. The effectiveness and limitations of these new systems in suppressing ballistically induced fires is unknown.

With FY02 funding, the 46 OGOGM/O–AC (WPAFB) will conduct parametric controlled-damage testing of a simulated H–60 Halon 1301 engine nacelle suppression system. The Aircraft Engine Nacelle (AEN) simulator will be modified to representative H–60 dimensions and environmental conditions. These tests will be used to determine damage effects and suppression agent design concentrations within the nacelle, determine possible vulnerabilities as input for follow-on APG engine nacelle tests, and to provide leveraging opportunities for Halon alternative agent tests. In FY03, NAWCWD will conduct controlled-damage and ballistic tests on the H–60 Halon 1301 engine nacelle suppression system. sAn H–60 engine nacelle with non-running engine and component clutter under representative environmental (airflow) conditions will be used. These data will provide input for follow-on (FY04) NAWCWD running engine/systems tests and will provide leveraging opportunities for Halon alternative agent tests. In FY04, NAWCWD will conduct ballistic demonstration/ data validation tests on an H–60 engine nacelle suppression system. An engine nacelle with operating engine and related nacelle systems under representative environmental (airflow) conditions will be used. These tests will help to identify locations vulnerable to ballistically induced fires and will also provide leveraging opportunities for Halon alternative agent tests. The

U.S. Air Force project engineer for this effort is Mr. Pat O'Connell and the Navy project engineer for this effort is Mr. Joe Manchor. ■

Mr. Jeffrey Wuich, an associate at Booz Allen Hamilton, supports the Survivability/Vulnerability Information Analysis Center (SURVIAC) in the Joint Live Fire (JLF), Live Fire Test & Evaluation (LFT&E), and JTCG/AS programs. Prior to working for Booz Allen in support of SURVIAC, Jeff served as an officer in the U.S. Air Force as an aerospace engineer at WPAFB, Ohio. Jeff received his B.S. in Aerospace Engineering (1988) from Iowa State University and his M.S. in Mechanical Engineering (1992) from the University of Dayton. He is a member of the National Defense Industrial Association (NDIA).

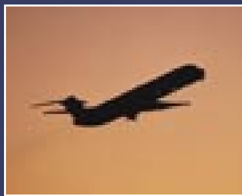
Mr. Tracy Sheppard is the Technical Director of the Washington Office of the Center for Strategic Analysis, University of Texas (UT) at Austin. Prior to joining the research faculty of the University of Texas, Tracy served for 15 years within DoD, first as a Marine and then in positions at Aberdeen Proving Ground and within the office of the Deputy Director for OT&E/LFT in the Pentagon. Tracy received his AS and Bachelor of Eletrical Engineering degrees form the Johns Hopkins University in Baltimore, Maryland.

Figure 5. Tri-Service H–60 helicopter engine nacelle ballistic fire suppression evaluation

Figure 6. H–60 Helicopter series tail rotor subsystem ballistic vulnerability tests

Figure 7. H–60 Helicopter series improved durability gearbox (transmission) run-dry and ballistic vulnerability tests

Figure 8. C–130 LAST® armor quantification



Commercial Aircraft Vulnerability Assessment

and Threat Mitigation Techniques

by Mr. Howard J. Fleisher

The Federal Aviation Administration (FAA) initiated the Commercial Aircraft Hardening Program (CAHP) in 1990 in direct response to the 1988 bombing of Pan American Airlines Flight 103, the directives of the President's Commission on Aviation Security and Terrorism, and the mandates set forth in the Aviation Security Improvement Act of 1990. The program was re-confirmed by the Presidential Commission on Aviation Safety and Security in 1996 and again in the Aviation Security and Transportation Act of 2001, which transferred program responsibility to the Transportation Security Administration. The overriding goal of the program is to protect commercial aircraft from catastrophic structural or critical system failure due to an in flight explosion or other terrorist initiated event. The program has been focused on determining and identifying the minimum size explosive that would result in aircraft loss. The data collected in this research is being used to validate and refine explosives detection standards for checkpoints, checked luggage and cargo. Methods and techniques that can be applied to the current and future fleet of commercial aircraft to decrease the level of vulnerability to internal explosive effects are also being studied. Finally, in addition to internal explosive threats, the CAHP assesses other intentional threats to the aircraft including electromagnetic interference, projected energy, man portable air defense systems (MANPADS), and small arms fire.

Vulnerability Assessment

Working with aircraft manufacturers and the Department of Defense (DoD), the CAHP is researching the effects of internal blast on the current and future fleet of commercial aircraft. Since 1992, the program has conducted over 100 explosive tests on commercial aircraft structures, including a joint test on a Boeing 747 with the United Kingdom, a test with the Boeing Company on an L1011 aircraft, and tests on DC–9, Boeing 727 and 737, and Airbus A300 airframes.

In addition to the full scale airframe tests, supporting data tests have been conducted, allowing researchers to characterize the properties of luggage and luggage containers on explosive properties and expected fragmentation profiles. This information has been useful in the development of analytical models and has provided a means to allow for interpolation and extrapolation of test results to other initial conditions.

The data and assessments generated from the test program has allowed the CAHP to develop a family of aircraft survivability curves, each dependent upon aircraft and threat type. These curves can then be used to determine if explosives detection standards are appropriate and, if not, to what extent they may need revision.

Mitigation

The aircraft vulnerability assessments and testing have provided sufficient data to enable the CAHP to identify, investigate, and develop measures that increase the survivability of commercial aircraft to internal explosive detonations. Concepts investigated include explosive mitigating liners and hardened containers, commonly known as hardened unit load devices (HULDs).

HULD research was initiated as a result of the Aviation Security Improvement Act of 1990. Initial efforts were aimed at determining the technical feasibility of incorporating blast mitigating features into a predetermined container geometry at a reasonable unit tare weight. This

Figure 1. Typical aircraft explosive vulnerability test (DC–9, 2002)

entailed the development of analytical models and full-scale explosive testing of standard container designs as well as prototype hardened containers. Once the feasibility was proven, performance specifications and design validation protocols were developed.

In order to obtain security approval, a candidate blast resistant container design is subjected to three different tests, including component testing to establish that fragmentation resistance requirements are satisfied, and shock holing to establish that materials are strong enough to withstand shock loads from an explosive detonation in close proximity to the material surface. Finally, a full-scale explosive validation test is conducted in which the container is positioned within a wide-body aircraft cargo hold and loaded with an explosive device which is then detonated. In order to pass this requirement, the container must maintain its integrity and cause minimal damage to the surrounding aircraft structure and systems.

The explosive threat that is required to be contained by the HULD exceeds the charge size specified in the Criteria for Certification of Explosives Detection Systems in order to provide a margin of safety. In addition to the security requirements, HULD's are also required to conform to existing airworthiness and airline operational requirements. Current focus has been on the LD–3 classification of container, which are the most common type of passenger luggage container currently used on wide-bodied aircraft. The CAHP has conducted 41 explosive validation tests of various HULD prototypes since 1992.

In 1998, a HULD designed by Galaxy Scientific Corporation (see Figure 2), became the first to satisfy the FAA's security requirements. In 2001, Telair International became the second manufacturer to pass the security validation tests (see Figure 3).

The current goal of the hardened container project is to assess the structural and functional readiness of HULD designs and investigate both the operational and cost effectiveness of implementing hardened containers as a security measure. Unit tare weight, life cycle cost and maintainability remain the key issues.

The Future

The CAHP continues its role as a test-centered activity with a transportation security critical mission. Vulnerability assessment work allows for the identification of measures and criteria for both the prevention (screening) and mitigation of threats.

As new threats to civil aviation evolve, the CAHP will continue to determine their effect on commercial aircraft structure and systems, and identify countermeasures as appropriate. ■

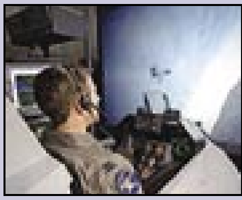
For the past 5 years, Mr. Fleisher has worked for the Office of Transportation Security Research and Development (now part of the Transportation Security Administration), located at the FAA William J. Hughes Technical Center outside of Atlantic City, New Jersey. He has provided technical expertise in the areas of commercial aircraft vulnerability assessment, mitigation of explosive effects, and air cargo security. Mr. Fleisher has been serving as Manager of the Aircraft Hardening and Threat Mitigation Program since 2001, a program whose scope has expanded since the tragic events of 9/11. Mr. Fleisher was the Program Lead for Air Cargo Security Research and Development from 1998–2001.

Prior to his employment with the FAA in 1997, Mr. Fleisher spent 6 years working for Galaxy Scientific Corporation, a company specializing in Aviation Technology Research and Development, where he was the Program Manager of the Structural Vulnerability Group. During his tenure at Galaxy, Mr. Fleisher led the project team which developed the first blast resistant aircraft luggage container to successfully pass FAA explosive validation testing.

Mr. Fleisher has received a Bachelors of Science degree in Mechanical Engineering from the University of Pittsburgh, a Masters degree in Mechanical and Aerospace Engineering from Rutgers University, and a Masters degree in Business Administration from Rutgers University.

Figure 2. Galaxy Scientific Prototype HULD

Figure 3. Telair International Prototype HULD



The Use of Managed Flight Simulators

to Support Aircraft Vulnerability Studies and Analyses

■ by John K. Maniond

The Department of Defense (DoD) has developed sophisticated test and evaluation mechanisms to support the development and fielding of survivable weapons systems. These mechanisms include vulnerability analysis, which measures the inability of the weapons system to withstand damage from man-made threats. Vulnerability analysis uses well-defined tools and processes to evaluate the system level response to damage effects and explore conditions not tested due to resource and safety issues. The results of vulnerability studies directly influence system design by measuring overall vulnerability (e.g., vulnerable area) and determining the major contributors to vulnerability. Many modern weapons systems actually have a vulnerable area specification that requires a vulnerability analysis to demonstrate compliance. The vulnerability analysis, backed with ballistic testing, must prove that the system meets or exceeds those specifications. If vulnerability reduction measures are necessary, the major contributors to vulnerability identified through the vulnerability analysis are used to aid in the prioritization of vulnerability reduction concepts. Therefore, the vulnerability analyses results have a significant impact on the development of the weapons system. It is therefore paramount to ensure that all of the elements of the vulnerability analysis process are as accurate as possible.

In performing a vulnerability analysis on aircraft, the threat driven damage and failures are compared to performance requirements to estimate the ultimate effect of the failures on the weapon system's ability to maintain controlled flight and/or continue its mission. In many cases, a critical element in determining the end effect of threat-induced damage is the aircrew's response to the damage. Obviously, the ballistic testing process cannot directly measure crew responses due to personnel safety issues. The final vulnerability evaluation often must estimate crew response based on crew interviews, historical data, and operational documents. However, these sources are often insufficient in providing a definitive answer. Improvements to the accuracy of determining crew response to damage are therefore necessary to ensure adequate vulnerability reduction measures are designed into the system.

The use of high fidelity, manned flight simulators to support training has been proven to be a critical element of the training process. This training results in crews more capable of successfully completing their mission and surviving to fight again. A crucial element of that training is the ability to generate realistic failures and malfunctions. Typically, failures are introduced at the discretion of the simulator instructor and tend to have little or no correlation with actual threat effects. While this type of training is useful in addressing normal operational malfunctions, it does little to prepare the student for actual combat damage. Real threats can cause multiple failures, which can be exacerbated by inappropriate crew action. To ensure that crews are trained and ready for combat, it is necessary to include realistic damage and failures into the simulated mission.

This article discusses a concept that interfaces elements of the manned flight simulator and vulnerability analysis processes to enhance both areas. The concept is called the Real-time Endgame Analysis of the Lethality Induced by Threat Effects (REALIT–E; pronounced ***reality***) concept.

The REALIT–E concept enhances both the vulnerability analysis and training processes by merging the strengths of each. Through the REALIT–E process, the damage generated from vulnerability testing and analysis is integrated into the high fidelity training simulator giving aircrews realistic cues to threat induced damage. The results of the aircrew responses to damage help fill the vulnerability data voids and allow a better evaluation of the end effects of the damage.

The Vulnerability Analysis Process

The basic elements of the vulnerability analysis process are shown in Figure 1 (see page 27). Vulnerability analysis starts at the point where the aircraft has been hit. As shown in Figure 1, a hit may result in physical damage to the platform. The vulnerability analysis utilizes testing, modeling, simulation, and existing data to determine the expected damage that results from various hits on the platform. The physical damage affects the platform's components by either degrading them, failing them completely, or causing them to become threats themselves (e.g., burning fuel). Again, testing and experimentation of damaged components combined with modeling and simulation provide the tools necessary to support this step in the vulnerability analysis process. The degraded components, likewise, degrade the overall system performance. The system-level degradation can be estimated through testing and experimentation, aircraft design and performance information,

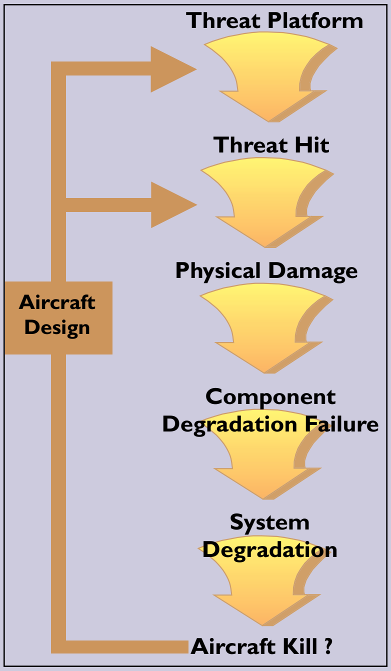


Figure 1. Elements of vulnerability analysis

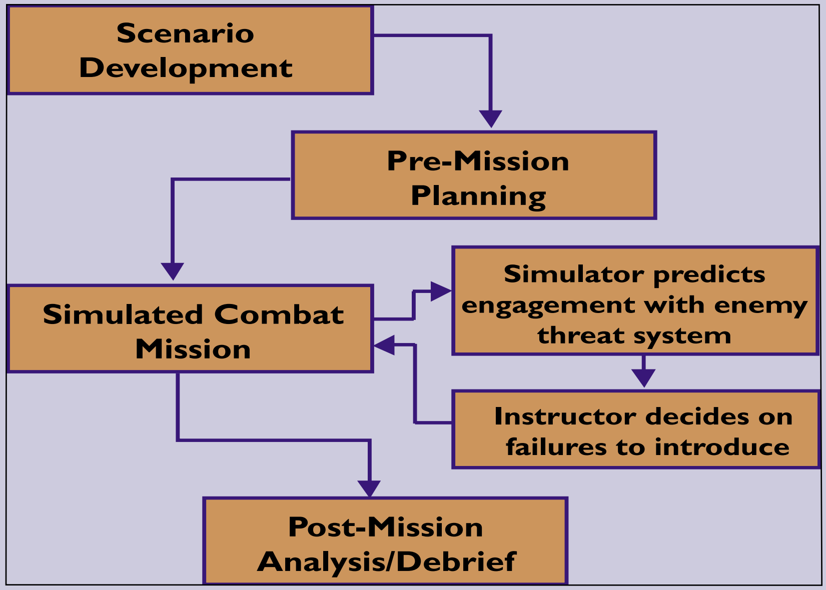


Figure 2. Simulation-based training process

and modeling and simulation. The last step in the vulnerability analysis process is determining the impact of the system-level degradation on aircraft performance requirements and assessing whether or not a "kill" has occurred. Some system-level responses are clearly a kill, such as the aircraft exploding in a fireball. But some system-level responses are not as easily resolved into a kill or no-kill condition. For example, the loss of a single engine in a twin-engine helicopter while in hover could cause the aircraft to impact the ground and result in a forced-landing kill. But if the crew responds quickly enough, they may be able to transition the helicopter to forward flight without losing too much altitude, thus avoiding the forced-landing kill. Clearly in this case, the crew response is key in determining the probability of the resulting forced-landing kill.

Issues

The process of estimating the end effect of the failures on aircraft performance often must consider the crew's reaction and response to the damage. Crew reaction is typically addressed by reviewing historical data on combat incidents, interviewing aircrews, reviewing aircraft flight manuals, and reviewing aircraft specifications.

Historical combat data are useful in that they relate real combat damage to loss or recovery of aircraft. The limitations of these data are that details of the threat engagement tend to be sketchy at best and any survivable combat damage is, understandably, fixed quickly without much record of the original damage.

Interviews with aircrews are useful in that the perspective of the pilot is directly integrated into the analysis. Their experience and knowledge is extremely valuable for assessing the impact of damage and failures. The limitation of these data is that pilot responses tend to be optimistic and may underestimate the potential for aircraft loss due to a number of factors including task saturation and loss of situational awareness.

The emergency procedures in the aircraft flight manuals are another useful source of data. They clearly describe the procedures to follow given sets of damage. The limitation of this information is that it is developed for latent failures expected to be encountered based on reliability considerations. The multiple, cascading, and time-dependent failures associated with combat damage are not considered.

Aircraft specifications contain information on expected performance under certain conditions and provide a useful tool in determining system response to some failures. The limitation of these data is that the specifications do not consider all of the potential changes in aircraft performance that can result from combat damage.

All of these data sources, while valuable in supporting the decision of determining aircraft kill are insufficient in giving a complete answer. In the end, the analyst and/or engineer must decide the impact of crew reactions to damage on aircraft survivability.

The Manned Simulator Training Process

A typical simulation-based training scenario is illustrated in Figure 2. The instructor pilot develops the training scenario by considering the training requirements, tactics to be tested, systems involved, and pilot experience. For this task, the instructor relies on training and aircraft manuals, doctrines, and flight records. After the instructor defines the mission and scenario, the crew performs the pre-mission planning by considering the mission goal and profile, tasking, assets involved, threat profiles, and system capabilities. After the plans are made, the crew enters the simulator and flies the mission. During the mission, the simulator models aircraft performance, environmental effects, and interactions with threat systems. The crew responds to all of the stimuli in an attempt to successfully complete the mission. If a threat system engages the aircraft, the crew responds to try to avoid the hit. If a hit occurs, the instructor may introduce failures and observe the crew response. Often these failures are introduced at the discretion of the instructor with little or no considerations for the threat, attack aspect, or hit point. Upon mission completion, or termination, the instructor debriefs the crew. This debrief includes discussion of the mission performance, systems management effectiveness, and effectiveness of crews reactions and contingencies.

Issues

A crucial element of simulation-based training is the ability to generate equipment and system failures or malfunctions that require the crew to analyze the source of the failures and take appropriate steps to initiate a corrective action. These failures typically have little or no correlation with actual threat effects. While this type of training tests the ability of the student to exercise the Emergency Procedures (EP) in the context of a mission, it does little to prepare the student for the actual damage effects caused by real threats. Real threats differ in that they may cause multiple failures that are seemingly unrelated and create cascading, time-dependent, and/or crew-action-dependent failures.

REALIT–E Concept Description

The REALIT–E process is designed to address the vulnerability analysis and manned simulator training process issues by taking advantage of the strengths of each process. For vulnerability analysis, REALIT–E directly addresses the aircrews' responses to damage by using the information available from multiple manned flight simulator sessions. This provides statistically significant information to support the determination of the end effects of damage for vulnerability analysis. In return, REALIT–E provides realistic damage

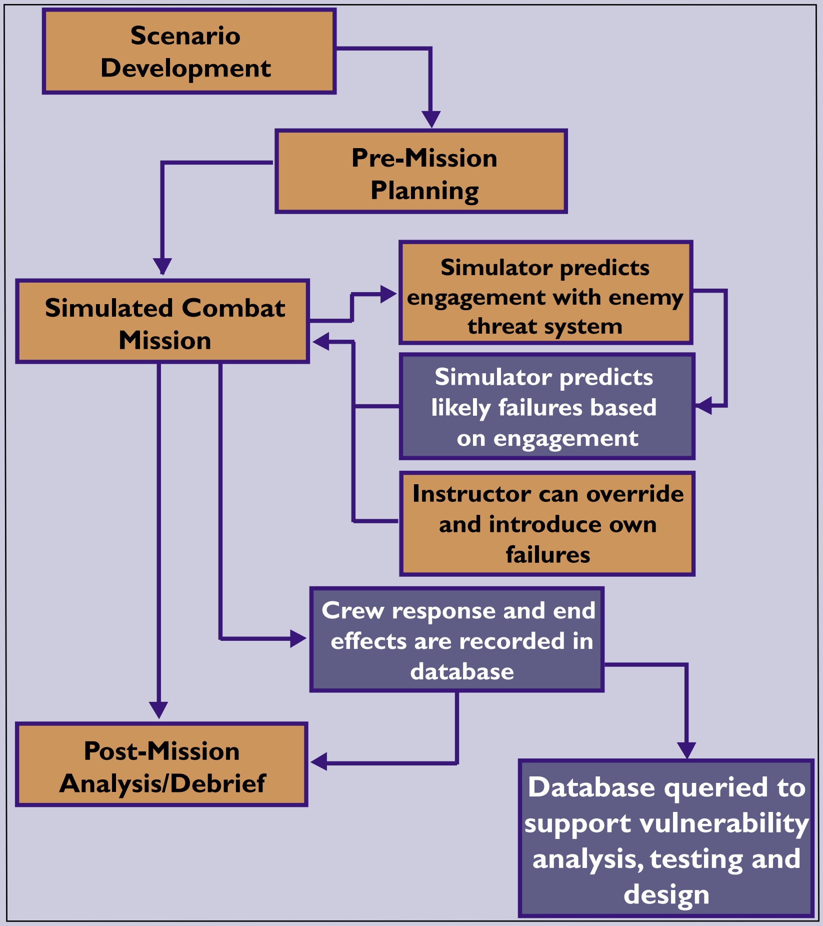


Figure 3. Simulator training process using REALIT-E

cues to the aircrew during the mission, which enhances crew training.

The REALIT–E process compiles the vulnerability information offline to generate a matrix of possible system and component failures based on threat type and engagement parameters. To create this matrix, vulnerability data are generated and formatted for the threat systems of interest using standard vulnerability analysis processes and tools. Vulnerability analysis determines probable damage and failure mechanisms for a given threat endgame condition. The endgame condition in this case is defined as direction of impact with respect to the aircraft, inherent threat properties (e.g., mass, warhead properties, etc.), and threat properties as a result of the engagement (e.g., velocity, orientation, hit point, etc.). For a given endgame condition, component failures are determined and the respective system-level degradations are identified. Through the REALIT–E process, these derived threat effects are mapped to the available simulator malfunctions to allow a real-time implementation in the simulator. If, during a simulated mission, a threat engagement leads to a "hit," the pre-mapped malfunctions will be injected based on the threat and endgame conditions. The inserted malfunctions will allow for the consideration of time dependency of failures, failures caused by subsequent crew actions, and cascading effects. The REALIT–E process will still allow for the instructor to inject his/her own sets of malfunctions or he/she can select from a predefined list of realistic, threat-specific failures. Through REALIT–E's automated data acquisition software, parameters of the engagement will be measured, collated, and stored into a pilot and aircraft response database. This database will enhance post-mission debriefs and will directly support vulnerability analysis by providing a statistically significant database of crew responses to damage. A concept of the simulation-based training process that includes REALIT–E is shown in Figure 3, where the REALIT–E specific elements are shown as shaded boxes.

REALIT–E

Developing the vulnerability data and matrix of system failures does not require the development of any new tools. It simply uses the standard tools and processes in place for over 30 years. The process of mapping the system failures to simulator malfunctions will require coordination between the vulnerability engineers and simulator engineers and will most probably require software modifications to the simulator. Other aspects of implementing the REALIT–E process that will require simulator software modifications are for automatic insertion of failures and automatic data acquisition. Additional offline software tools are also required for the post mission analysis and integration back into the vulnerability analysis process.

Benefits

The primary benefit, which is actually what spawned the REALIT–E concept, is the improvement to the vulnerability analysis process. The data from the REALIT–E database will directly support vulnerability evaluations by providing real aircrew responses to real damage. This information will allow for the final determination of the impact of the damage on aircraft performance. This will give more accurate and defendable evaluations of aircraft vulnerability, which will result in more survivable aircraft.

The second, and most direct benefit of the REALIT–E process is on aircrew training. This process exposes crews to realistic damage effects in the context of real mission profiles. It trains the aircrews to think beyond the standard emergency procedures in the heat of the battle. It also exposes the crew to the realistic cues of damaged systems and the degraded performance characteristics. This results in a level of realism that currently can only be experienced during combat. This gives the aircrew an expanded understanding of their aircraft, which provides the edge to allow the crew to continue the fight and/or safely return to base.

Other Potential Uses of REALIT–E

The REALIT–E process will provide benefits throughout the design and life-cycle of the weapons system. This includes support for LFT&E ballistic test analysis, support for operational testing and evaluations, support for tactics, techniques, and procedure (TTP) development, and support for advanced aircrew training.

The ballistic testing process follows a process similar to the system level vulnerability assessment. In this case, the damage is inflicted by a real ballistic event resulting in a system level response. The test engineer must identify the damage and the system response and ultimately make a decision as to the end effect of the damage on the aircraft. Like the vulnerability analysis process, this includes consideration of aircrew response to the damage. Through the REALIT–E process, the damage and failures can be mapped into a simulator and crews can fly and experience the damage under realistic mission profiles. The end effect of the crews' responses can be measured and used directly to support test data analysis.

Following the developmental testing phase, the operational testing (OT) phase requires an independent vulnerability evaluation of the platform. If the REALIT–E process was applied to support ballistic testing analysis during developmental testing, the OT evaluators will have the damage and failures available to experience for themselves in operationally significant mission profiles. This will give them a first hand understanding of the aircraft's vulnerability and allow them to make more informed decisions. The developmental testing data and information generated using the REALIT–E process, combined with the OT evaluator's testing of the data in the simulators, will provide data to directly support the independent system level vulnerability analysis. Therefore, the benefits of REALIT–E are amplified during the OT phase since the evaluators will make more informed decisions based on better data and information. Also, during the OT testing phase TTPs to mitigate the effects of ballistic damage can be developed and integrated into the emergency procedures.

Finally, once the system is fielded, the damage and failures developed throughout the design, testing, and analysis of the system can be integrated into the training devices to provide advanced training to aircrews. This will give crews an added dimension to their training by providing ballistically derived failures that they normally would only experience in combat. By providing this information in a safe environment, the crews can learn how to deal with the damage and be better prepared to face the challenges of combat.

Summary

The REALIT–E process provides a framework to enhance two seemingly disparate areas, vulnerability analysis and aircrew training. This process improves the vulnerability analysis process by providing real aircrew responses to given sets of damage and improves the training process by exposing aircrews to realistic, threat specific, damage. It opens the door for additional cross fertilization between the survivability and training communities that can improve aircraft design, tactics, mission rehearsal, etc.

A rudimentary implementation of the REALIT–E concept was actually performed in support of the vulnerability assessment of a U.S. aircraft. It clearly enhanced the vulnerability assessment, and the feedback received from the aircrews indicated that the benefits to training would be substantial. REALIT–E is currently only a concept, and the full extent of the benefits has yet to be realized. ■

John Manion recieved a B.A. in Mechanical Engineering in 1987 from the University of Pittsburgh. He then spent 10 years working for the U.S. Navy in combat aircraft survivability. His work for the US Navy included numerous survivability studies in support of Naval aircraft design. After 10 years in the Government, he left to become the Air Systems Lead of the Studies and Analysis Group at the SURVICE Engineering Company. He may be reached at john@survice.com.

Former Survivability Test Assets

Used to Sharpen the Skill of the Warfighter

■ by Mr. Richard Mueller and Lt Col Anthony Brindisi

During the week of 20–24 May the Weapons Survivability Laboratory (WSL) at China Lake supported the Joint Services Air Defense Lethality Team (JSADLT) in a one week training session. The JSADLT is a team of reservists from all three Services sponsored by the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS). Their function is to collect data on aircraft combat damage and losses. This data is essential to current and future aircraft as it reveals vulnerabilities in our existing aircraft that we can fix and provides a database of lessons learned for future aircraft designs. The WSL provided the facility and test assets for the training. In addition, the WSL provided a two-hour demonstration of foreign andit-aircraft artillery (AAA) rounds and their effect on an aircraft target.

The JSADLT provided training in Combat Data Collection to a combination of reserve and active Service members. In attendance was the Air Force's 940th Combat Logistic Support Squadron (CLSS). This group of experts in aircraft battle damage repair was asked to join the training, not only to demonstrate actual live fire testing against U.S. combat aircraft, but for the JSADLT to learn from another group of experts how they assess damage to aircraft. The JSADLT lead, Lt. Col. Anthony Brindisi stated that, "China Lake is a superb location for this training because it has the widest selection of aircraft damage replicating combat damage, which provides us with the most realistic training." During the course of the week-long training, the JSADLT was able to inspect damage from both missile and ballistic threats. In addition to metal structures, damage to composite structures was infused into the training, reflecting the latest in aircraft materials.

The AAA demonstration was designed to provide the added bonus of allowing the trainees a first hand view (via TV monitors) of various foreign AAA threats in action. Several armor piercing-incendiary (API) and high explosive-incendiary (HEI) cannon rounds were fired into an existing aircraft test asset. Digital high-speed film of each shot was recorded and each trainee was provided with a CD containing the video files for future reference.

During the conflict in Southeast Asia the Battle Damage Assessment and Reporting Program (BDARP) was initiated to collect aircraft combat damage data. The purpose of such a project was to provide data on actual damage and effects, and locate any possible vulnerabilities. Methods of reducing these vulnerabilities could be investigated and an engineering solution implemented as a "quick fix" in the field. This database also serves as a reference for designers of new aircraft.

The combat database supported the drive to test aircraft with live munitions prior to operational deployment. This was later put into the congressionally mandated Live Fire Test (LFT) law. The WSL at China Lake serves to meet the requirements of the LFT law for the U.S. Navy and U.S. Marine Corps. Such live fire testing has paid enormous dividends in the design of more survivable aircraft, as was demonstrated in Operation Desert Storm. During this operation several F/A–18 and A–10 aircraft returned safely to base after having suffered major structural damage from surface-to-air missiles and AAA.

Following the secession of hostilities in Southeast Asia, the BDARP program was disbanded. Recent conflicts have shown to be short in duration and sporadic. Thus, several conflicts have occurred without the combat damage reporting system in place with the subsequent loss of valuable data. The JSADLT was setup as a reserve unit that would be ready to collect data at a moment's notice. In between active service they have been tasked with providing training to pilots/aviators and battle damage repair personnel. The AAA demonstration and WSL test assets provided the team an

JSALT Team training at China Lake's WSL

opportunity to expand their knowledge and practice their skills.

The WSL served as the training base for the JSADLT's latest training venture due to its many damaged aircraft from live fire testing. These former test assets provided a "schoolroom" for the analysis of real ballistic and missile damage. This marriage of testing and training has been promoted via the Live Fire Testing and Training Initiative (LFT&TI), who funded the AAA demonstration.

The JSADLT described the China Lake training sessions as a great success and hope to make it a bi-annual event. In retrospect, this training was another good example of how scientists and warfighter can team together to benefit one another, and in this case, even across services. ■

Lt Col Anthony Brindisi is the senior reservist for the 46th Test Wing at Wright Patterson AFB, Ohio. He has a B.S. degree from Parks College of Aeronautical Technology and holds an M.S. from the University of Southern California. In his civilian life, Tony has over 20 years of aircraft susceptibility reduction experience, primarily as a Low Observable engineer working both in industry and for the Government. Having been active in performing combat data collection and analysis during Operation Allied Force, he now leads the Joint Service Air Defense Lethality Team, coordinating efforts with the U.S. Army, U.S. Navy, and U.S. Air Force to perform combat data collection. He may be contacted at anthony.brindisi@wpafb.af.mil.

Mr. Richard Mueller is an aircraft vulnerability reduction engineer at the Naval Air Warfare Center-Weapons Division (NAWCWD), China Lake, CA. He has participated in live fire ballistic testing of the V–22 joint-service aircraft and Joint Live Fire MANPADS testing. Current work includes research on new fire protection technologies, funded via the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS). In addition to the DoD activities, he has conducted testing for the FAA to support the Uncontained Engine Debris Damage Analysis Model (UEDDAM) through the Catastrophic Failure Prevention Program (CFPP). He holds a Bachelor's degree in Aerospace Engineering from Texas A&M University (1999). He may be reached at muellerrb@navair.navy.mil.

Initial FY 04 Joint Aircraft Survivability Project Submission Schedule

Below are the initial planning dates for the Joint Aircraft Survivability FY 04 Program Build. A finalized list will be published in the next issue of the newsletter.

January

21–24	JACG Meeting, Orlando, FL
27–30	Winter PMSG/OSD Guidance Meeting

April

8–11 (TBD)	Principal Members VTC Guidance Meeting
8–11 (TBD)	Subgroup VTC Planning Meeting

May

5–9	Subgroup Planning Meeting (Location TBD)

June

6	Subgroup Chairs submit prioritized lists to Program Office
27	SOWs due to Program Office

July

11	Program Office forwards proposals to PMSG and Advisory Group

August

1	Advisory Group returns inputs to Program Office
19–22	Summer PMSG Meeting, Seattle, WA

FY03 JTCG/AS Program

An Overview

by Mr. Jim Buckner

As we start out fiscal year 2003, the JTCG/AS will fund 15 new projects and continue funding to completion four Group projects, 11 Survivability Assessment projects, 9 Vulnerability Reduction projects and 8 Susceptibility Reduction projects in addition to supporting the Central Office overhead.

The JTCG/AS is organized to perform work in those technical areas supporting combat aircraft survivability. These areas are susceptibility reduction, vulnerability reduction, and survivability assessment. The susceptibility reduction area's emphasis is on technologies which will prevent the aircraft from being hit by threat weapons. In the vulnerability reduction area the emphasis is on technologies which will improve the survivability if the aircraft is hit by a threat weapon. Finally, the survivability assessment area addresses all of the methodologies and simulations necessary in the development of aircraft, which require the evaluation of expected threats.

A short description of the projects approved for funding and recognition of the JTCG/AS members who are doing the work is given below. Many of the ongoing efforts have been reported on in earlier issues of this magazine.

Susceptibility Reduction

In FY03 the Susceptibility Reduction Subgroup (SRSG) will complete it's **evaluation of Aerogels** as a retrofitted material for thermal and infrared emission suppression in and around aircraft engines in temperature regimes from 250–1500° F. This project has been ongoing since FY01 at Wright-Patterson Air Force Base (WPAFB), the Naval Air Warfare Center Weapons Division (NAWCWD) at China Lake, California, and the Army Aviation Technology Directorate (AATD) at Fort Eustis, Virginia. The principal engineer on this project has been Mr. Lenny Truett at WPAFB with U.S. Navy assistance by Mr. Leo Budd at NAWCWD and U.S. Army assistance by Mr. Malcolm Dinning at AATD.

Another project the SRSG will complete in FY03 is **Miniaturized Countermeasures (CM) for Unmanned Aeronautical Vehicles (UAVs)** which intends to demonstrate the ability to effectively balance platform signature, threat warning, and countermeasures while not impacting payload and air vehicles. Mr. Jim Young at NAWCAD is in charge of this project. Another project Jim Young has is the **Active Acoustic Cancellation for UAVs** project. The effort is to demonstrate the ability to reduce the acoustic signature of UAV platforms through the use of low cost receivers, digital signal processing chip sets, and sound generation systems. The concentration will be on horizontal shaft push/pull propeller driven aircraft.

Dr. Robert Shortridge, of the Naval Surface Warfare Center Crane Division (NSWCCD) at Crane, Indiana, is working on a project to leverage the recent successful use of **Ultrafine Aluminum (UFAL)** as a burn rate accelerant in propellant formulation. This effort is expected to improve the effectiveness of decoy flare CM solutions against advanced infrared (IR) seeker threats.

At the Naval Research Laboratory (NRL) Mr. Richard Moore heads up the **Joint Service Surrogate Seeker** project with Mr. Frank Hayes at the Missile Guidance Directorate within AMCOM at Redstone Arsenal. This effort is building a programmable, surrogate imaging seeker for service lab and field use to aid in the assessment of aircraft survivability techniques to counter imaging seekers. Mr. Moore also heads up the **Imaging Seeker Aim Point** project, which is working to use M&S and real time hardware tools developed by the Services to assess the survivability impact on the imaging seekers ability to acquire Low Observable (LO) targets at long range.

Also at NRL, Mr. Vincent Cassella is in charge of the **Tier II/III Laser Susceptibility** project scheduled for completion in FY03. The objective of the effort is to develop laser based Directed Infrared Countermeasures (DIRCM) techniques and determine requirements to defeat the advanced threats on the second and third tier threat lists. The threat lists are the targets for several SRSG developmental efforts and include "must defeat" threats (Tier I) and would like to be capable of defeating Tier II and III. Tier II and III are those threats that were not available when the systems began development.

Mr. Christopher Cole of the U.S. Army's Intelligence Information Warfare Directorate at Fort Monmouth, New Jersey is in charge of the **Solid State Laser Pointer** project. This effort is developing a solid state device that will be capable of pointing a laser beam in a solid angle with a high degree of precision and investigating possible techniques for implementation and integration on an aircraft platform.

There are four new starts for FY03 within the SRSG. The first is the **Special Materials Aero Urban Decoy (SMAUD)** project, under Mr. William Taylor at the Air Force Research Laboratory (AFRL). This government/industry team will develop an aerodynamically stable SMAUD which is reliable, economical, and safe for deployment at low altitude environments and can protect low flying large fixed wing aircraft. It will be inexpensive to produce (less than $150 per unit) and be capable of being dispensed from current operational dispensers.

The next SRSG new start is the **High Power Wideband Array** project headed by Dr. Stephen Schneider at AFRL. It will develop and fabricate a brass board wideband aperture array capable of transmitting high power. The wide bandwidth of operation would allow several jamming systems to be combined into one aperture, resulting in a decrease in the weight and space requirements as well as a reduction in the cost of ownership of Navy and Air Force combat and support aircraft.

The third new start is the **Laser-Focal Plane Array (FPA) Effects Modeling for Laser CM Optimization** project. John Keat from the U.S. Army Aviation and Missile Command is heading this project up with contractor participation from Mike Porter of Dynetics, Inc.

The final new start in FY03 is the **Imaging Infrared Seeker CM Susceptibility Study** project. This project is under Frank Hayes from the U.S. Army Aviation and Missile Command. And will investigate the effectiveness of a short pulse, Band IV laser in combination with flares (cooperative jamming) to defeat Imaging Infrared (IIR) seekers.

Vulnerability Reduction

One of the most promising ongoing projects within the Vulnerability Reduction Subgroup (VRSG) is the **Survivable Engine Control System Demonstration,** more commonly referred to as the SECAD project. The engineer on this project is Mr. Charles E. Frankenburger, III from NAWCWD at China Lake. A significant gain in single engine aircraft survivability can be obtained with a survivable engine control (SEC) system. Traditional adaptive control techniques have been developed to detect minor changes in engine performance and mitigate the effects due to a deteriorating engine (normal wear and tear) by implementing small adjustments to the engine control schedules. The objective of this effort is to expand the damage detection algorithms developed under the project to a full envelope design. Validation of the methodology will be demonstrated in an engine test. Principle customers are intended to be F/A–18 E/F (PMA 265) and the Joint Strike Fighter (JSF).

Mr. Alex Kurtz (46th Test Wing) and Mr. Leo Budd (NAWCWD) are teaming on another potentially valuable project for the V–22 and the JSF aircraft. It is the **Weapons Bay Ablative Protection "Proof of Concept"** effort. The objective is to reduce the vulnerability of combat aircraft from a ballistically impacted burning munition and to obtain critical protection data on a full-scale weapons bay.

Mr. Greg Czarnecki from the 46th Test Wing at WPAFB is our MANPADS expert. In FY03 he heads up the **MANPADS Impact Point Assessment** project with in assistance from Mr. Al Boyd (MSIC, Redstone Arsenal), Mr. David Payne (STRICOM, Redstone Arsenal), Mr. Gary Johnson (White Sands Missile Range), Mr. David Edwards (46th Test Wing at Eglin AFB), and Mr. Terry Dougherty (NAWCWD). The objective of this project is to validate the ability of MANPADS flyout/endgame M&S methodologies to discriminate between adjacent IR targets and predict hit points.

Mr. Czarnecki, in conjunction with Dr. David Barrett at NAWCAD, is also conducting the **Dynamic Loading Methodologies** project. Current loading methodologies do not reconfigure to correctly represent in-flight loads. Ground loading methodologies fail to consider damage-induced changes to the flutter envelope that can lead to premature failure. The new ground loading procedure and complimentary flutter analysis will support live fire testing and assist in the generation of reliable and complete test assessments and vulnerability analyses. Anteon, Inc. has determined an optimum modeling technique to use for analysis and is developing a means of dynamically testing skin-spar joints under asymmetric high-strain rate conditions which will combine analytics with testing. A final report on this project is due this year.

The **Bonded Wing Survivability Demonstration** project is a cooperative program being funded by the JTCG/AS and Bell Helicopter Textron, Inc (approximately 50%-50%). Mr. Nicholas Calapodas of the U.S. Army Aviation Applied Technology Directorate (AATD) at Fort Eustis is the project engineer. This project will fabricate a section of the V–22 wing using bonded composites technology to co-cured skin/stiffeners and bonded wing ribs. The project will conduct ballistic and structural post-ballistic testing. The program is derived from the recently concluded Design and Manufacture of Low Cost Composites-Bonded Wing (DMLCC) program which was also jointly sponsored by Bell Helicopter Textron and the Government. A 24-feet V–22 wing section has been designed and manufactured, and successfully underwent static and fatique testing. The objective of this program is to demonstrate the structure's ballistic survivability.

Nick Calapodas is also in charge of the **Advanced Survivable Rotorcraft Validation** project and is assisted by Greg Czarnecki and Dave Barrett. The first objective of this effort is to enhance the technology base to design hardened rotorcraft structures against large ballistic threats—to include MANPADS—and remain within acceptable weight and cost requirements. The next objective is to validate a low cost/weight MANPADS hit-point biasing concept. In the first case, ballistic testing is highly desirable and in the second MANPADS testing is mandatory. The JTCG/AS anticipates that the Joint Live Fire program will assist with the performance of this program. Participating contractors are Bell Helicopters, Boeing Helicopters, and

Sikorsky Aircraft (Rotary Industry Technology Association).

Mr. J. Michael Bennett from the 46th Test Wing at WPAFB is in charge of the **Intumescent "Instant Firewalls" for Low-Cost Fire Protection** project. Intumescent materials respond to impingement of a fire by swelling and forming a protective char that physically protects the structure. The objective of this project is to demonstrate and optimize the utilization of intumescent technologies to form "instant firewalls" to control, contain, and manage damage-related fires in compartments. In FY03 the most promising variants developed in FY02 will be stepped up to entire intumescent rings to be used in the full-scale Engine Nacelle Test Facility at WPAFB.

Another Fire and Explosion Protection effort is the **Ionomer "Self-Healing" Fuel Containment** project under Mr. Richard Mueller at NAWCWD. This project will determine the feasibility of using an ionomer plastic in place of self-sealing rubber in a fuel cell, or as a retro-fit enhancement in the form of a backing board. The effort is co-funded by the Naval Air Combat Survivability Program (NACSP).

The VRSG has **seven new starts in FY03**. In the first new-start, Boeing Phantom Works in Seattle is working under contract with Greg Czarnecki's office on the **Reduced Aircraft Vulnerability to MANPADS** project. The objective of this effort is to develop near-term aircraft vulnerability reduction solutions for military aircraft impacted by shoulder-fired MANPADS missiles. This is a follow-on to the MANPADS BAA which started in FY00. The goal is to develop affordable modifications to existing fleet aircraft that reduce MANPADS vulnerability and develop innovative MANPADS vulnerability solutions that have not been previously demonstrated.

Mr. Joseph Manchor of NAWCWD is in charge of the second new start—**Simple Passive Extinguisher (SPEX)** project. This effort is to develop, fabricate, and demonstrate a simple, low cost, lightweight, passive fire extinguishing system to provide improved protection for aircraft dry bays (aircraft voids and spaces adjacent to a fuel source). Commercial-off-the-shelf (COTS) fire suppression technologies will be tested to demonstrate their application to this concept. This is a one year effort to demonstrate a new concept to enhance dry bay fire protection.

The third new start is the **Rod Warhead Damage Assessment & Analysis** project headed up by Greg Czarnecki. The objective is to generate projectile/penetration data necessary for assessing aircraft vulnerability to continuous/discrete rod warhead projectiles and then to advance damage prediction methodologies involving rod-projectile impacts.

Mr. Richard Mueller of NAWCWD heads up the fourth new start which is the **Aerogel Hydrodynamic Ram Mitigation** project. This project is expected to complete in FY03. It's objective is to determine and demonstrate the potential for Aerogels to mitigate hydrodynamic ram shock damage to fuel containment/support structure.

Mr. Kevin Nolan of AATD will initiate the fifth new start with the **Armor Attachment Techniques** project. The objective is to develop quick and permanent attachment techniques that interface with the composite structure to attach opaque armor(s) to composite aircraft structure. Over a period of four years the project will acquire or build a state-of-the-art composite structure to be used for parasitic attachment techniques. It will design and build a composite structure with integrated attachments; conduct an analytical analysis; procure armor materials; conduct ballistic tests and dynamic load tests and analyze data, document findings and lessons learned, create a CD of models developed and write a final report.

The sixth project is the **Rotary Wing Aircraft Battle Damage Repair—Study of Repair Effectiveness and Durability** project. It is headed by Mr. Robert L. Laughman at the U.S. Army Evaluation Center (AEC) and supported by Mr. Richard Jackson at the U.S. Army Aviation Logistics School. The objective is to examine 2–3 primary Army Aircraft Battle Damage Repair techniques for the longevity under flight loading/flight conditions to establish the length of time the repair technique can be expected to perform in operational flight hours. The project is expected to be completed in FY05.

The seventh and last VRSG new start in FY03 is the **UAV Vulnerability—Predator Analysis** project. Pat O'Connell from the 46th Test Wing at WPAFB and Jim Young from NAWCAD are teaming on this project. The objective is to demonstrate to the Unmanned Aerial Vehicle (UAV) and the Unmanned Combat Aerial Vehicle (UCAV) community, using the Predator UAV, the value of using aircraft vulnerability analysis techniques to increase the survivability of their platform. In FY03 a FASTGEN model of the Predator will be built and the component P_k data base will be populated with Predator P_k values.

Survivability Assessment

In FY95 the JTCG/AS and the JTCG/ME jointly began the development of the **Advanced Joint Effectiveness Model (AJEM).** AJEM has been developed to be the single DoD standard tool capable of evaluating the vulnerability of aircraft, missiles, and ground mobile vehicles and assessing the lethality and effectiveness of munitions against those vehicles. To accomplish this AJEM has been under strict configuration management. Also, AJEM must be deemed credible through a rigorous accreditation process. AJEM is currently in use however, all desired methodologies for inclusion in AJEM have not yet been included and these methodologies must be accredited before becoming part of the AJEM product. A Configuration Control Board (CCB) has been established for AJEM to manage changes and improvements. In FY03 the JTCG/AS will fund a comprehensive vulnerability assessment model within AJEM to include an Encounter module, Graphical User Interface (GUI), analysis tools, visualization, and online documentation.

Until AJEM is fully operational, the legacy models it is designed to replace have to be maintained. Mr. Kelly Kennedy with the Aeronautical

Systems Center (ASC) at WPAFB is in charge of the COVART/FASTGEN CCB project. This project performs on-going maintenance and miscellaneous support for users and those developing test cases for COVART and AJEM test case comparisons. These models are used to generate target vulnerability data. Codes are used for either weapon system vulnerability or lethality. JLF and LFT&E predictions are also required.

The SURVIAC Model and Simulation (M&S) Accreditation Support Information project under Ms. Michelle Kilikauskas at NAWCWD provides a credibility assessment of the models and simulations which are distributed by SURVIAC and are documented in the form of standard Accreditation Support Packages (ASPs). ASPs are a three volume set of documentation which provides a model status overview, a functional characterization, and detailed verification and validation (V&V) results. By establishing accreditation support data in the standard ASP format, new model users with unique requirements can add to the body of knowledge about the model by simply adding change pages to the ASP reports.

Major Chris Bakke from the U.S. Air Force Studies and Analyses Agency (AFSAA) oversees the **SURVIAC Model Manager Support** project. The objective of this effort is to provide model manager support for the JTCG/AS models in SURVIAC. The models are—

- Enhanced Surface-to-Air Missile Simulation (ESAMS), Air-to-Air Combat Models
- Advanced Low Altitude Radar Model (ALARM), Radar Directed Gun Simulation (RADGUNS)
- Advanced Joint Effectiveness Model (AJEM), the fly-out model BLUEMAX IV
- Directed RF Energy Assessment Model (DREAM)
- Computation of Vulnerable Areas and Repair Time (COVART), Fast Shot-line Generator (FASTGEN)
- In the near future, the Joint Threat Engagement Analysis Model (JTEAM)

The Model Deficiency Report (MDR) process will be maintained and model users will be promptly advised of software changes for their version of each SURVIAC model. SURVIAC is the Survivability Information Analysis Center managed under contract by Booz Allen and Hamilton.

The BEARD Standardization, Phase 2 project is under the overall leadership of Mr. Dwight FitzSimons from the National Ground Intelligence Center (NGIC) in Charlottesville, Virginia. BEARD is an acronym for the following JTCG/AS models: BLUEMAX, ESAMS, ALARM, RADGUNS, and DIME. Mr. FitzSimons is the program manager for RADGUNS. BLUEMAX is under Mr. Stephen Ames from ASC, ESAMS is under Lt Michael Etan from the U.S. Air Force Information Warfare Center (AFIWC) at San Antonio, Texas, and ALARM is under Mr. Steven Hoberty from AFRL. DIME has released its last new version and is no longer participating in the standardization efforts. The common software module and standards development includes all RF environmental effects, RCS representation, coordinate systems, flight paths, physical constraints, random number generator, software standards, etc. The BEARD models comprise five of the core set of tri-service survivability codes that are distributed by SURVIAC. Contractors involved with the standardization efforts in BEARD are Booz Allen Hamilton (SURVIAC), SAIC, Dayton, and TRW.

The **Fuze Simulation Investigations** project under Ms. Eun-Joo Ketcham at NAWCWD will provide standard fuze codes for RF and EO threat proximity fuzes that are usable with both JSEM and AJEM for insertion into SURVIAC. Proximity fuze function prediction is a critical element in the simulation of an engagement between an aircraft target and an attacking missile system. These simulations are products of leveraging from on-going fuze simulation projects. This project will demonstrate the use of a near field code to accurately predict fuze function for a complex target.

Mr. Martin Lentz from the 46th Test wing at WPAFB is the responsible engineer for the DBFM/WINFIRE Model Enhancements project. The objective of this project is to develop and maintain, together with the JTCG/ME, a standard dry bay fire model and a fuel tank ullage explosion model for stand alone analysis and future insertion into the AJEM. The DBFM/WINFIRE model will provide the framework to enable modeling of physical threat/target interactions that cannot be done within current models such as hydrodynamic ram filling the dry bay, fire pooling and spread, airflow within the dry bay with clutter, time dependent damage, and synergistic effects.

Under Mr. Frank Hayes and Matthew Lawrence at the Aviation and Missile Command at Redstone, Alabama the Susceptibility/Vulnerability to Anti-Helicopter Mines project has developed a deliverable baseline Generic Re-configurable Anti-Helicopter Mine Model (GRAHMM). In FY03 the focus will be on establishing credibility in the model through actual AHM hardware and helicopter flight tests. Emphasis will be on modeling engagement scenarios and comparing predictions to controlled real world test results. The customers for this model are rotorcraft program managers/developers concerned with survivability evaluation of their aircraft against widely proliferated AHMs and countermeasure developers charged with identifying effective means to protect aircraft from these threats. This would include PEO Aviation and associated helicopter PMs, U.S. Navy helicopter PMs and potentially UAV PMs, Army Research Lab, and U.S. Naval Research Laboratory. The contractor involved in this effort is Dynetics, Inc. of Huntsville, Alabama.

Mr. Roy Randolph of NAWCWD is the lead on the Integrated Survivability Analysis project with SURVIAC support. The objective is to develop an Integrated Survivability Assessment (ISA) process for DOT&E applications. The process will combine survivability operational test and evaluation (OT&E) with Live Fire Test and Evaluation (LFT&E) results to provide an overall survivability assessment of a system under test. The approach will integrate the proper roles of modeling and simulation (M&S) with test and evaluation (T&E).

Lt Michael Etan of AFIWC and Mr. Brent Waggoner of NSWC Crane, Indiana are teamed on the **SAM Model Credibility Assessment** project. This project will leverage available flight test data for functional and model-level evaluation of the ESAMS model. It will also identify, understand, and document differences between ESAMS and JMASS for identical SAM engagements. The customers are the current ESAMS users and future JMASS users who perform surface-to-air missile (SAM) threat analysis. This group consists of over 100 organizations in the Department of Defense and industry, including: JSF, F/A–18E/F, B–1B DSUP, NAWC, NSWC, AFIWC, AFSAA, Boeing and Lockheed-Martin.

The Component Vulnerability Analysis Archive (CVAA) CCB project is a computerized component vulnerability archive that includes engineering methodologies, results of completed analyses, and all available test data on component vulnerability due to any non-nuclear mechanism. In FY03 the deliverables will include between 5 and 15 additional component vulnerability data sets integrated into an updated version of the CVAA. Data sets will be sought from current CVAA users and identified by SURVIAC from all available sources, including planned LFT&E and JLF tests, and will be approved by the Joint Component Vulnerability Project Executive Committee in accordance with JTCG/AS–98–M–003.

The Survivability Assessment Subgroup (SASG) has four new projects starting in FY03. The first is the **Fire and Explosion Modeling and Simulation Capability Certification** project headed up by Marty Lentz at the 46th Test Wing in WPAFB, assisted by Dr. R. Reed Skaggs at Aberdeen Proving Grounds, Maryland. The objective of the project is to enhance and validate computational models describing ignition, fire growth, and fire suppression. This validation will increase the model credibility and become part of the V&V for the Fire Prediction Model or FPM/WINFIRE—and other available fire CFD models.

The next new start is the **Simulink ADA Model Requirements** project headed up by Mr. FitzSimons from NGIC. This project will develop a plan to meet aircraft survivability, mission planning, and other DoD requirements for the next-generation air-defense artillery (ADA) Model. A new Simulink-based ADA model is currently in the early stages of development by NGIC and its contractor Ball Systems. The new model is almost entirely based on RADGUNS modeling methodology.

DREAM is the Directed Radio Frequency (RF) Energy Assessment Model. The DREAM Verification for Entry into SURVIAC project is to perform initial verification and validation (V&V) of the model sufficient to enter it into SURVIAC as a category 2 model.

The final new start for the Survivability Assessment Subgroup (SASG) is the Imaging infrared (IIR) Sensor and Laser Effects Model Development project. The project will develop a modular Imaging Infrared (IIR) sensor model that incorporates; optical effects, Focal Plane Array (FPA) effects, data and signal processing, guidance, tracking, environmental effects, spatial representations, and laser countermeasure effects. The project is managed by Frank Hayes and John Keat from the Aviation and Missile Command, Redstone Arsenal, Alabama. Contractor for the effort is Dynetics, Inc. at Huntsville, Alabama.

Group Projects

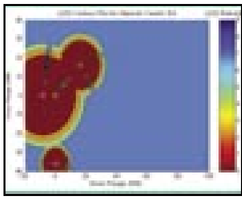
The program is funding four projects in FY03 which do not rightfully fall into either of the three subgroups above so they are placed in the "Group Projects" category. The **Textbook Support** project under Philip Weinberg is simply a project to provide funding for the purchase of the second edition of the Aircraft Survivability Textbook when published. The **JTCG/AS Magazine** *Aircraft Survivability* project under LCDR Andy Cibula, Central Office Director, provides the resources necessary to publish this magazine.

The Joint-Service Air Defense Lethality Program is a unique project utilizing both U.S. Air Force and U.S. Navy reserve personnel. The objective of the project is to develop the capability to send uniformed personnel into the field to capture combat damage data and document the damage so that it can be put in SURVIAC and be available for data reduction and analysis by the community. The U.S. Air Force portion of the program is headed up by Lt Col Anthony Brindisi, USAFR while the U.S. Navy portion is headed up by Captain Jeff Ard, USNR. Lt Col Brindisi's unit is stationed with the 46th Test Wing at WPAFB and Captain Ard's unit will work with Mr. Ken Goff's survivability division at NAWCAD.

Finally, the **Naval Postgraduate School (NPS) Survivability Support** project provides limited funding to enable CDR Mark Couch, USN, who is the survivability department head at the school, to develop a web-based self-study version of the NPS survivability course A 3251 and to conduct distance training by way of video teleconferencing. The distance training was started in FY02 with much success and will be continued.

There were many other candidate projects for FY03 submitted in the screening and selection process. Only the ones selected for funding this year are included in this article. The JTCG/AS Central Office is the program office for Joint Aircraft Survivability and is located in Crystal City in Arlington, Virginia. Funding to accomplish these projects is provided by the Deputy Director, Operational Test and Evaluation, Live Fire Test and Evaluation (DDOT&E(LFT&E)). The JTCG/AS is chartered by the Joint Aeronautical Commanders Group (JACG) and receives oversight from the JACG and DDOT&E(LFT&E). ■

Mr. Jim Buckner received a Bachelor of Science (BS) degree in Naval Science from the U.S. Naval Academy and a Master of Business Administration (MBA) degree from National University in San Diego, California. After his service in the Navy he spent four years with Armament Systems, Inc. In 1981 he became the support contractor to the JTCG/AS Central Office.



Network–Centric Electronic Attack Evaluation

A Methodology

■ by Dr. Paul Wang, Mr. Mitchell Sparrow, Mr. Myron Greenbaum, Mr. Ken McKenzie, and Ms. Ami Patel

The current evolution from a platform-centric to a network-centric approach to warfare presents significant challenges for the development of advanced support jamming systems. New tools will be required to fully address the added complexities of a network-centric approach integrating a geographically dispersed capability of platforms, sensors, and electronic attack (EA) elements. Previous platform-centric EA systems required assessment of a single jamming aircraft and multiple integrated air defense system (IADS) radars. Network-centric EA requires assessment of multiple jamming platforms, of differing capabilities, attacking various combinations of the IADS. ITT Industries' Avionics Division, together with Modern Technology Solutions Incorporated (MSTI), has recently worked to develop a modeling and simulation methodology to study and evaluate network-centric EA approaches being considered for a range of applications. The methodology makes use of both new and existing digital models to evaluate EA and provides quantitative measures of effectiveness. This article will describe the two models and how they are used on a sequential basis to evaluate network-centric EA approaches being considered to degrade elements of an IADS.

EA systems currently being considered for possible development and deployment include large aircraft stand-off, tactical sized aircraft for both stand-off and escort, unmanned vehicles for escort and stand-in, and unmanned systems for close-in operations. Capacity of these platforms will range from thousands of pounds and tens of kilowatts of available prime power down to several pounds and a few watts. Operating ranges for the EA platforms can range from stand-off ranges of hundreds of miles to close-in ranges down to less than a mile. These constraints and those parameters associated with the IADS radars and platforms to be protected provide for an extensive trade-space. In order to optimize network-centric EA from both a platform and payload stand-point, tools are needed to effectively "navigate' this trade-space. That was the impetus that led to the development of the methodology described in this article.

Methodology

The developed methodology is based on the use of two digital models: the ITT Industries developed Network Centric EA (NC–EA) Model and the standard Extended Air Defense Simulation (EADSIM) model. The former is used to determine EA effectiveness through the radar jamming equation and the latter is used to quantify effectiveness in the protection of specific aircraft and flight paths through the average number of missiles launched. The NC–EA model allows the examination of the EA trade-space, and once a network of EA capabilities has been selected, their effectiveness can be quantified using EADSIM.

Network-Centric Electronic Attack (NC–EA) Model

The NC–EA Model creates and displays an "effectiveness map" of the battle area that includes the IADS lay-down and the EA platforms and their locations. The threat radars are described by their location, transmit power, transmit antenna gain, and side-lobe levels. The EA platforms are described by their location and flight path, effective radiated power (ERP) (product of transmit power and antenna gain), and losses. The map (typically covering 80 x 120 NM) is segmented into appropriated down-range and cross-range cells (typically 1 x 1 NM) and the radar jamming equation is used to derive the jam-to-signal (JSR) in each cell for a given strike platform radar cross-section (RCS). In the case of multiple jammers radiating against the same radar, a composite JSR is computed. The "effectiveness map" displays the JSR over the battle area using a color overlay to display the effectiveness of the jamming (e.g., JSR>6 dB-Blue; JSR>3 dB-Green; JSR>0 dB-Orange; JSR<0 dB-Brown).

To illustrate the potential application of the NC–EA model, consider the following example. A squadron of attack aircraft protected by a NC–EA team is dispatched to attack a specific target defended by an enemy IADS grid. With the target located at (0 0), the enemy IADS consists of two Surface-to-Air Missile (SAM) sites and an early warning radar as listed in Table 1 (see page 38).

The NC–EA assets include stand-off, escort and close-in jammers. Jammers' locations and ERP's of these assets against individual radar threats are listed in Table 2 (see page 38).

Assuming the attack aircraft have a radar cross section (RCS) of A dBsm, the jamming effectiveness maps generated by the ITT NC–EA model are illustrated in Figure 1. Figures 1a to 1e illustrate the jamming effectiveness of the NC–EA assets against individual radar threats (R1 to R5), while Figure 1f illustrates the composite effect of the entire jamming strategy. Using this map, the squadron of attack aircraft (A dBsm RCS) are expected to be well protected and can move freely in the "blue" region (75 percent of the total area of interest). With careful planning, this squadron can fly within 20 – 25 NM of the intended target.

The ITT NC–EA model can also be used to evaluate the impacts of the attack aircraft's RCS on the jamming effectiveness. The evaluation indicates that using a more stealthy aircraft (B dBsm), the "blue" region increases to 90 percent, and the attack aircraft can easily reach within 5 NM of the target safely. From the above discussion, it is clear that the ITT NC–EA model can be used effectively for pre-mission planning and support jamming effectiveness analysis and assessment. It also has the capability to be used for real-time NC–EA jamming assets re-alignment and re-assignment during a military mission.

Extended Air Defense Simulation (EADSIM)

The Extended Air Defense Simulation (EADSIM) is an advanced, Department of Defense (DoD) standard analytic model. It is capable of modeling one versus one as well as many versus many engagements for complex attack and air defense scenarios. It provides the ability to model threats, sensors, jammers, and weapons to a high level of fidelity, to include command and control relationships and networks.

EADSIM radars are calibrated to NC–EA through parameters such as transmit power, antenna mainlobe gains and sidelobe levels, signal-to-noise ratio, and reference detection range. Complex antenna lobing patterns are then added to EADSIM radars to replicate threat radar characteristics. These complex azimuth and elevation patterns ensure the bi-static geometry of support jamming is considered. EADSIM jammers are calibrated to NC–EA jammers to achieve the consistent J/S and burnthrough ranges between the models. Jammers currently are modeled as noise jammers, but more complex jamming techniques can be employed. EADSIM jammers are defined by their effective radiated power, beam size, frequency limits, and power/time management scheme against multiple victim radars.

Once the NC–EA model output is calibrated in EADSIM, a many versus many IADS laydown with threats and blue systems is created. The complex IADS interactions of Blue and Red actions and countermeasures are assessed. EADSIM offers a number of options in outputting engagement events. Typical measures of merit include time in track, number of missiles launched, number of missiles reaching end-game, and probability of kill. Jamming effectiveness at the mission level is then determined from these results.

The EADSIM analysis considered a trade matrix of two Radar Cross Sections (A dBsm and B dBsm) and two jamming cases (with jamming and without jamming). In each case, four aircraft were flown from south to north as depicted by the black line in Figure 2. These aircraft flew at an altitude of 8,000 meters MSL and 350 Knots true airspeed. The jammer aircraft flew short orbit legs an altitude of 8,000 meters. The threat range for both SAMs was assumed to be 75 KM (40 NM).

Figure 2 (page 39) shows the effectiveness of the jammer in reducing the detected area for the A dBsm aircraft. The magenta area is where the aircraft can be detected with or without the presence of jamming. The blue regions represent areas where the aircraft can be detected when jamming is not present. One can see that even with jamming, the aircraft flightpath must fly in the detection coverage of one of the SAM radars. Figure 3 (page 39) shows that jamming allows the flightpath of the B dBsm aircraft to avoid detection by all SAM acquisition radars in the scenario.

Figure 4 (page 39) shows the quantitative results of this sample analysis. The baseline (i.e., no jamming) results show 37 SAM shots for an A dBsm target and ~23 SAM shots for a B dBsm target. As indicated in the results, the current jamming strategy reduces shots but is not completely

	Cross Range, NM	Down Range, NM
Target	0	0
R1, SAM 1, Tracking Radar	0	0
R2, SAM 1, Acqu Radar	0	-8
R3, SAM 2, Tracking Radar	16	16
R4, SAM 2, Acqu Radar	16	16
R5, Early Warning Radar	-36	0

Table 1. An exemplar IADS system

	Cross Rng	Down Rng	Jam vs R1	Jam vs R2	Jam vs R3	Jam vs R4	Jam vs R5
Stand-off	40	80	50 KW	25 KW	50 KW	25 KW	1 KW
Escort	10	20	10 KW	2.5 KW	10 KW	2.5 KW	
Close-In 1	7	-7	100 W				
Close-In 2	7	-7		100 W			
Close-In 3	9	9			100 W		
Close-In 4	9	9				100 W	
Close-In 5	-37	7					50 W

Table 2. An exemplar NC–EA assets

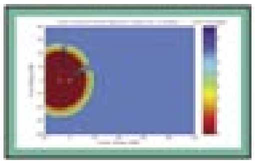


Figure 1a: Jam vs R1

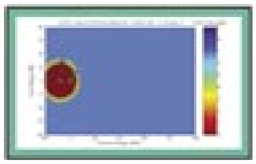


Figure 1b: Jam vs R2

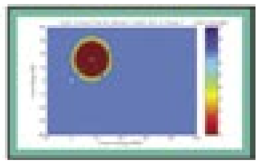


Figure 1c: Jam vs R3

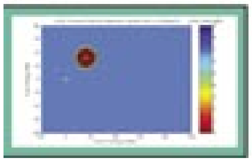


Figure 1d: Jam vs R4

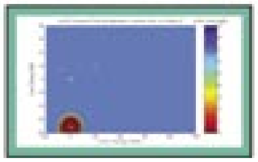


Figure 1e: Jam vs R5

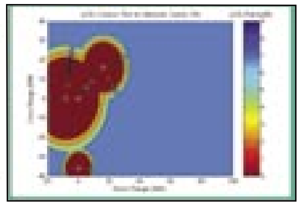


Figure 1f: Composite Jam Map (Blue = 75%)

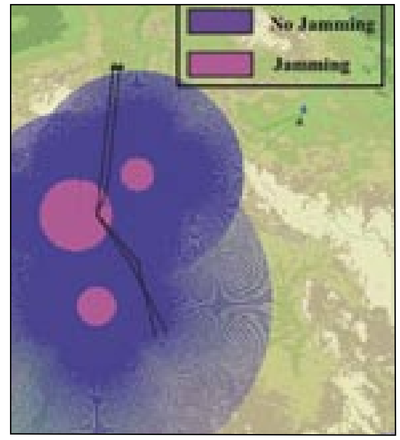


Figure 2. EADSim jamming effectiveness map (Attack A/C A RCS)

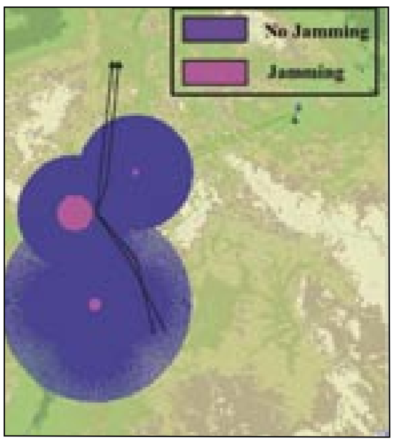


Figure 3. EADSim jamming effectiveness map (Attack A/C B RCS)

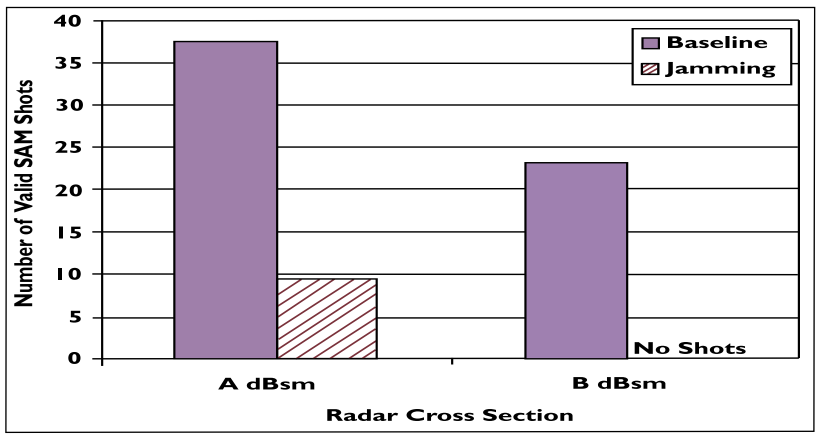


Figure 4. Average number of valid shots per aircraft

effective for an A dBsm target. Figure 2 confirms that even with jamming, there is still coverage for an A dBsm target by the acquisition radar (R2), thus incurring a small number of shots. The jamming strategy at B dBsm does become effective, resulting in no valid shots against the aircraft.

Summary

Two models have been employed to develop and evaluate Network-Centric Electronic Attack for use against IADS complexes. The effects of EA systems sizing and platform employment can be assured on a preliminary basis using the NC–EA model. Once the NC–EA performance complement is determined, detailed evaluation can be obtained using the standard EADSIM model and Measures of Effectiveness (MOEs) such as the average number of missiles launched can be determined. ■

Dr. Wang is currently a Senior Technical Consultant at ITT Avionics. His expertise is in the area of advanced system concept development and digital signal processing as applied to military electronic systems. His interests include developing modeling and simulation tools and digital system models. He has a Ph.D. in Electrical Science from the State University of New York at Stony Brook.

Mr. Sparrow is currently a Senior Technical Consultant and Manager of the Advanced Technology Group at ITT Avionics. His group is involved in developing technologies, design concepts and system architectures which will enhance performance on a cost-effective basis against the evolving threat. He holds both a MSEE and MSEM from Steven's Institute of Technology.

Mr. Greenbaum is currently the Director of Advanced Systems at ITT Avionics. He is involved in the development of Advanced EW Systems. His interests include radar systems, technique development and modeling and simulation. He holds a MSEE from NYU and is a Licensed PE in New York.

Mr. McKenzie is a Senior Project Engineer at MTSI and is lead for operational analysis studies and focuses primarily on mission analysis issues. He has conducted numerous mission analyses for government and industry organizations using the EADSIM model. Mr. McKenzie also has operational experience with the U.S. Navy. He has a Bachelor's Degree in Industrial Engineering from the Georgia Institute of Technology.

Ms. Patel is a technical engineer for the operational analysis group at MTSI and is involved in the modeling of threat systems and CONOPS using EADSIM and other modeling and simulation software. She has supported a number of survivability analysis studies involving electronic warfare technologies. Prior to joining MTSI, Ms. Patel was involving in systems integration work for Army Materiel Command through Science & Engineering Associates. She has a BME from Drexel University.

Calendar of Events

DEC

2–5, Dallas, TX
2002 Defense Manufacturing Conference (DMC)
www.dmc.utcdayton.com

2–5, Orlando, FL
I/ITSEC Interservice/Industry Training, Simulation, and Education Conference
mss@veridian.com
www.itsec.org/poc.htm

9–12, Las Cruces, NM
Modeling and Simulation
newtonh@newtec.wsmr.army.mil, dubek@wsmr.army.mil

9–12, Gaithersburg, MD
5th International Military Sensing Symposium
fbajowski@ndia.org

11–12
UAV USA Conference 2002
www.uavusa.com

JAN

6–7, Nellis AFB, NV
JSEAD Conference
www.uavusa.com

6–9, Reno, NV
41st AIAA Aerospace Sciences Meeting and Exhibit
www.aiaa.org

13–17, Los Angeles, CA
Digital Avionics Systems
bgoodin@unex.ucla.edu, 301.825.3344

14–16, San Diego, CA
AFCEA/USNI Western Conference and Exposition
exhibits@jspargo.com

26–28, Monterey, CA
Tactical Wheeled Vehicles
www.aiaa.org

FEB

2–4, Los Angeles, CA
Spacecraft and Payload Pointing Systems
bgoodin@unex.ucla.edu, 301.825.3344

2–6, Albuquerque, NM
Space Technology: An Applications International Forum 2003
Mary Bragg, 505.277.4950

5–7, Los Angeles, CA
UAV Aircraft Design
bgoodin@unex.ucla.edu, 301.825.3344

MAR

4–6, San Diego, CA
13th Annual Advanced Technology Electronic Defense Systems (ATEDS) Conference
www.ateds.com

Information for inclusion in the Calendar of Events may be sent to:

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